Palestine Polytechnic University

College of Engineering

Department of Electrical Engineering

Design and Implementation of a Noninvasive Anemia Detection System Using Optical Approach

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List of Content

Chapter One : Project Introduction

Chapter Two : Physiological Background

Chapter Three : Theoretical Background

Chapter Four : Project System Design

Chapter Five : Implementation and Results

Chapter Six : Conclusions and Recommendations

الإهداء

الحَمدُلله الذي ما تَّم جُهد ولا خُتِمَ سَعِي إلّا بَفضله ، وَ ما تَخَطينا هذه العَقَبات وَ الصُعُوبات إلّا بَتوفيقه . . .

إلى مَن سانَدتني في صَلاتِها و دُعائِها ، إلى مَن سَهِرَت الليالي تُنيرُ دَربي ، إلى مَن تُشاركُني أفراحِي و أحزاني ، إلى نَبع العَطفِ و الحَنان إلى أجمَلِ ابتسامةٍ في حَياتِي ، إلى أروَع امرأة في الوجود . . . أمّي الغَالية .

إلى مَن عَلَّمني أنَّ الدُنيا كِفاحٌ و سِلاحُهَا العِلم و المعرِفة ، إلى الذّي لمْ يبخَل عليّ بإي شَيء ، إلى مَن سَعَى لأجلِ رَاحَتي و نَجاحي ، إلى أعظم و أعزّ رَجُلٍ في الكَون . . . أبي العَزيز .

إلى الذّين ظَفرتُ بِهِم هَديةً من الأقدارِ ، إلى رفاقِ دَربي في هَذه الحَياة ، سَنَدي و سَبب فَرحَتي و فَخري . . . إخوتي .

إلى مَن سَاروا عَلى نَهجِ الأنبياءِ ، وَ حَملوا أقدس الرِسالاتِ و أشرفها و أدّوها بأمانة ، إلى كلِّ مُعَلّم أفادنا بعلمِه ، من أولى مَراحلِ الدراسة حتّى هذه اللحظة . . .

إلى كُلّ مَن سَاهَمَ في تَقديمِ يَد العَون لَنا و شارَكنا الأمَلَّ حتّى النهاية . . .

نُقَدم لَكم مَشروع تَخرجنا الذي هو نَتيجة انجازنا العّلمي للسنوات التي قَضيناها معاً

مريم صلاح

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Abstract

The concentration of hemoglobin in the blood is an important physical condition parameter and a low level of hemoglobin in the blood is called anemia, as the World Health Organization has determined the level of normal hemoglobin concentration for people on the basis of age, sex and pregnancy status. One of the most common causes of anemia is nutritional deficiencies, especially iron deficiency, although deficiencies of folic acid, vitamin B12 and vitamin A are also important causes. Anemia may cause several diseases, including infectious diseases such as malaria, tuberculosis, HIV and infection parasitic.

Our goal in this project is to design a device to detect the presence of anemia in a non-surgical way, as this disease has become widely spread throughout the world and the World Health Organization has revealed that there are more than 1.6 billion people suffering from anemia, and that 42% of children under 5 years of age and 40% of pregnant women worldwide suffer from anemia.

This device aims to reduce infections that can spread due to the use of needles and also reduce pain, and may be needed for patients in emergency rooms, intensive care units and postoperative follow-up, in addition to the person's ability to use this device at home and without the need to specialists or doctors, which in turn makes it easy and inexpensive to follow up on the condition of the affected person on a continuous basis.

The design of this device requires a source to produce light with wavelengths of 940 nanometers (infrared), 650 nanometers (red), which are harmless to humans. On the opposite side of the source is the detector, which picks up the waves that pass through the finger. Then the captured waves are processed and the results are displayed on the screen.

ملخص المشروع

إنّ تركيز الهيموجلوبين في الدم عامل مهم للحالة الجسدية ويسمى انخفاض مستوى الهيموجلوبين الدم **بفقر الدم**, حيث أنّ منظمة الصحة العالمية حددت مستوى تركيز الهيموجلوبين الطبيعي للأشخاص على أساس العمر والجنس وحالة الحمل. ومن الأسباب الأكثر شيوعاً لفقر الدم حالات نقص التغذية، لا سيما نقص الحديد ولو أن حالات نقص حمض الفوليك وفيتامين (ب12) وفيتامين (أ) تعد أيضاً من الأسباب المهمة وقد يسبب فقر الدم عدة أمراض منها الأمراض المعدية مثل الملاريا والسل وفيروس نقص المناعة البشرية والعدوى الطفيلية .

هدفنا في هذا المشروع تصميم جهاز للكشف عن وجود فقر الدم بطريقة غير جراحية ، حيث أن هذا المرض بات منتشراً بشكل كبير و في جميع أنحاء العالم و قد كشفت منظمة الصحة العالمية عن وجود أكثر من 1.6 مليار شخص مصاب بفقر الدم, وأن 42% من الأطفال الذين تقل أعمارهم عن 5 سنوات و40% من النساء الحوامل يعانون من فقر الدم في كافة أنحاء العالم.

إن هذا الجهاز يهدف إلى تقليل العدوى التي من الممكن إنتشارها بسبب استخدام الإبر و أيضاً تقليل الألم ، و قد تكون هناك حاجة إليه للمرضى في غرف الطوارئ ووحدات العناية المركزة ومتابعة ما بعد الجراحة, بالإضافة إلى قدرة الشخص على استخدام هذا الجهاز في المنزل و بدون الحاجة إلى متخصصين أو أطباء ، و ذلك بدوره يجعل متابعة حالة الشخص المصاب بشكل مستمر أمر سهل و غير مكلف .

يتطلب تصميم هذا الجهاز مصدر لإنتاج الضوء بأطوال موجية 940 نانومتر (تحت الحمراء) ، 650 نانومتر (حمراء) و هي أمواج غير ضارة للإنسان . في الجهة المقابلة للمصدر يوجد الكاشف و الذي يلتقط الموجات التي تمر عبر الإصبع . ثم تتم معالجة الأمواج التي تم التقاطها و عرض النتائج على الشاشة .

List of Figures

List of Tables

Chapter One

Project Introduction

1.1 **Introduction**

1.2 **Motivation and Problem Statement.**

1.3 **Main Objective.**

1.4 **Literature Review.**

1.5 **Project Cost.**

1.6 **Project Action Plan.**

1.1 Introduction

This project discusses the idea of designing and implementing a device to detect the presence of anemia using non-invasive methods which is based on a pulse photometric measurement method.

Anemia is reported as a low hemoglobin or hematocrit where hemoglobin (Hb) is an important component of red blood cells also it is responsible for transporting oxygen to the rest of the body and returning carbon dioxide to the lungs.

Photometry is a technique that measures the concentration of organic and inorganic compounds in a solution by determining the absorbance of wavelengths of light.

In this way, we will get the percentage of hemoglobin in the blood, and thus know whether the person is anemic or not without the need to take a blood sample.

1.2 Motivation and Problem Statement

Nowadays it is difficult to use invasive methods to detect anemia for several reasons including using needles to take a blood sample, which causes pain and increases the possibility of infection an added disadvantage of this method is the delay between the blood collection and its analysis, which does not allow real time patient monitoring in critical situations. But a noninvasive method allows pain free continuous on-line patient monitoring with minimum risk of infection and facilitates real time data monitoring allowing immediate clinical reaction to the measured data.

The statistics from the World Health Organization show that about 1.62 billion people suffered from anemia of different degree in the world, anemia can cause a number of complications, including the following:

- Lasting fatigue leading to diminished productivity.
- Weakened immune system.

- Fast or irregular heartbeat.
- Heart failure.
- Problems during pregnancy, including fatigue, premature labor and problems with fetal development.
- Increased risk of postpartum depression **[1]** .

Because of these difficulties and risks that may be caused by invasive methods, and due to the importance of measuring hemoglobin for given an indication about the patient's condition, many studies and researchers have worked on developing the methods used to measure this variable. These methods are easier to deal with it, do not contain the complexity that involved in invasive methods devices, and are financially inexpensive as well.

1.3 Main Objective

The main objective of this project is to design and implement a device to detect the presence of anemia by measuring the concentration of hemoglobin in a non-invasive based on measuring the variance in absorbance of LED and IR light through blood by measuring the attenuation of signals through the index finger.

1.4 Literature Review

The traditional methods for detection of anemia involve an invasive approach requiring blood sampling and subsequent lab-based testing of hemoglobin concentration, hematocrit volume, and complete blood count (CBC). These procedures require access to diagnostic facilities and can be greatly time intensive with a substantial cost. Recent developments in this field have been made to increase both the portability and non-invasiveness of these sensors through using microfluidic-based sampling methods, optical attenuation methods, or light scattering-based measurement methods. Although these developments have greatly improved the approaches for the detection and diagnosis of anemia, there still exists a need for improvement in long-term user monitoring and size and cost reduction. Additionally, to improve the functionality of the point-of-care device in developing countries **[4]** .

A non-invasive technique enables for one-time or continuous hemoglobin monitoring with minimal risk of infection and discomfort. Several researchers have worked on developing non-invasive hemoglobin meters and some are still working to improve the accuracy of estimating non- invasive hemoglobin.

A project similar to this project was designed at Palestine Polytechnic University **in 2018**, entitled " **Design and Implementation of Portable Hemoglobin Concentration and Fat Percentage** " , but we have made some modifications and additions to it, our project will evaluate the results based on the ages and gender that the user can specify through the screen.

1.5 Project Cost

Table (1.1): Price of the project components.

Components	No. of component	Price ($)
IR LED	1	1.778
Red LED	1	0.642
OPT101 Detector	1	1.33
ICs	3	21.43
Arduino nano	1	11.74
9v 5500mAh lithium battery rechargeable	1	3.78
Resistors and capacitors	26	6
LCD	1	0.72
Total price	27	47.42

1.6 Project Action Plan

The project selection, formulation its ideas, identification a good previous studies and the collection for a basic information and documentation to starting up in the project were the most important tasks carried out at the first semester. **Table (1.2)** shows the distribution of the first semester over a period of (15) week. For done the project implementation and building, the automatic distribution of tasks needed to implement the project during the second semester. **Table (1.3)** shows the distribution of the second semester over a period of (15) week.

Table(1.2): Distribution of Tasks on the First Semester.

Week Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Finding Project Idea	🟩	🟩													
Proposal		🟩	🟩	🟩											
Search and Collecting data		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩						
Documentation			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Preparing for presentation													🟩	🟩	🟩
Print documentation															🟩

Week Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Collecting components	🟩	🟩	🟩	🟩	🟩										
Building and testing the system				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Analysis						🟩	🟩	🟩	🟩	🟩	🟩	🟩			
Documentation							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Preparing for presentation													🟩	🟩	🟩
Print Documentation															🟩

Table(1.3): Distribution of Tasks on the Second Semester.

After defining a general introduction to this study and explaining the project's motives, to begin implementing the proposed idea, it is first necessary to define the Circulatory System and the Main Parts of it , blood and hemoglobin and other Physiological informations, this will be explained in chapter two.

2

Chapter Two

Physiological Background

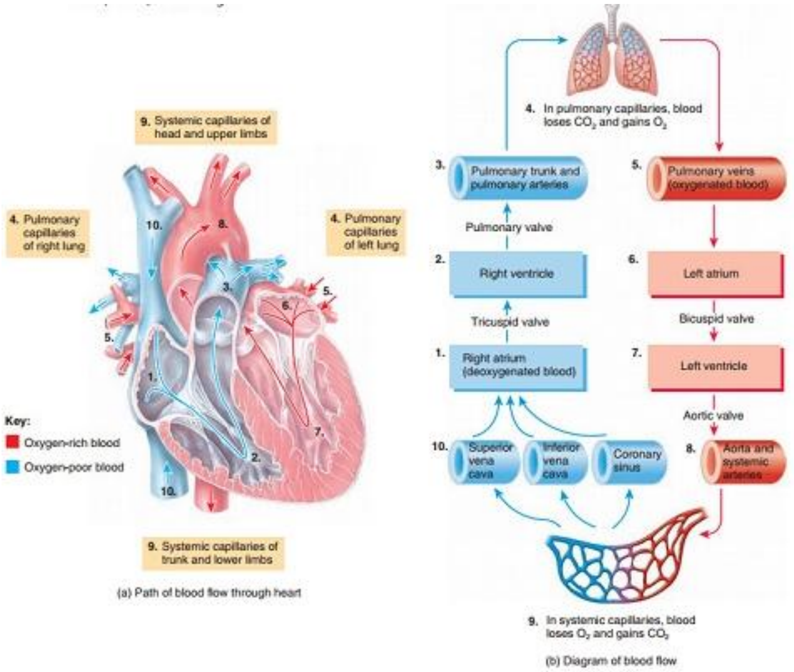
2.1 Circulatory System

2.1.1 Circulatory System Definition

The circulatory system is made up of the vessels and the muscles that help and control the flow of the blood around the body. This process is called circulation. The main parts of the circulatory system are the heart, arteries, capillaries and veins.

The blood begins to circulate; it leaves the heart from the left ventricle and goes into the aorta. The aorta is the largest artery in the body. The blood leaving the aorta is full of oxygen. This is important for the cells in the brain and the body to do their work. The oxygen rich blood travels throughout the body in its system of arteries into the smallest arterioles **[5]** .

On its way back to the heart, the blood travels through a system of veins. As it reaches the lungs, the carbon dioxide (a waste product) is removed from the blood and replace with fresh oxygen, as shown in **Figure (2.1)** .



(a) Path of blood flow through heart

(b) Diagram of blood flow

Figure (2.1): systemic blood flow through the heart **[6]** .

2.1.2 Circulatory System Main Parts

The main parts of the system as shown in **Figure (2.2)** are:

The heart, arteries, veins and capillaries.

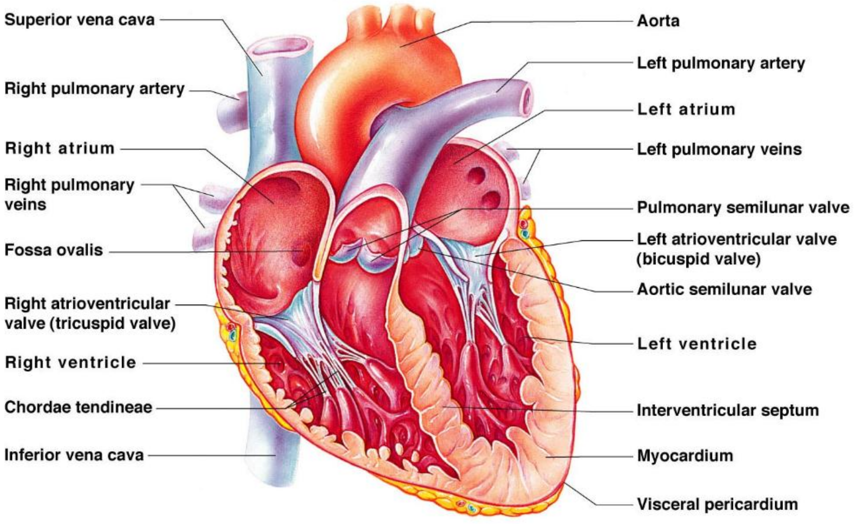


Figure (2.2): Internal anatomy of the human heart **[7] .**

2.1.2.1 Heart

The muscle that pumps blood received from veins into arteries throughout the body. It is positioned in the chest behind the sternum, in front of the trachea, esophagus, and aorta; and above the diaphragm muscle that separates the chest and abdominal cavities. The normal heart is about the size of a closed fist, and weighs about 10.5 ounces. It is cone-shaped, with the point of the cone pointing down to the left. Two-thirds of the heart lies in the left side of the chest with the balance in the right chest.

The heart is composed of specialized cardiac muscle, and it is four-chambered, with a right atrium and ventricle, and an anatomically separate left atrium and ventricle. The blood flows from the systemic veins into the right atrium, thence to the right ventricle, from which it is pumped to the lungs, then returned into the left atrium, thence to the left ventricle, from which it is driven into the systemic arteries.

The heart is thus functionally composed of two hearts: the right heart and the left heart. The right heart consists of the right atrium, which receives deoxygenated blood from the body, and the right ventricle which pumps it to the lungs under low pressure; and the left heart, consisting of the left atrium, which receives oxygenated blood from the lung, and the left ventricle, which pumps it out to the body under high pressure.

2.1.2.2 Arteries

Arteries are elastic, muscular tubes. These blood vessels operate at a high pressure to help transport oxygen-rich blood away from the heart and deliver oxygen, nutrients, and hormones throughout the body.

Arteries branch repeatedly to form microscopic arteries, known as arterioles Trusted Source, to distribute blood into capillary beds. Capillaries are blood vessels that carry blood to the body’s organs at a microscopic level **[8]** .

2.1.2.3 Veins

Veins carry the blood to the heart. The smallest veins, also called venules, are very thin. They join larger veins that open into the heart. The veins carry dark red blood that doesn't have much oxygen. Veins have thin walls. They don't need to be as strong as the arteries because as blood is returned to the heart, it is under less pressure.

Veins receive blood from the capillaries after the exchange of oxygen and carbon dioxide has taken place. Therefore, the veins transport waste-rich blood back to the lungs and heart. It is important that the waste-rich blood keeps moving in the proper direction and not be allowed to flow backward.

This is accomplished by valves that are located inside the veins. The valves are like gates that only allow traffic to move in one direction.

The vein valves are necessary to keep blood flowing toward the heart, but they are also necessary to allow blood to flow against the force of gravity. For example, blood that is returning to the heart from the foot has to be able to flow up the leg. Generally, the force of gravity would discourage that from happening. The vein valves, however, provide footholds for the blood as it climbs its way up.

2.1.2.4 Capillaries

Capillaries are very thin and fragile. The capillaries are actually only one epithelial cell thick. They are so thin that blood cells can only pass through them in single file. The exchange of oxygen and carbon dioxide takes place through the thin capillary wall. The red blood cells inside the capillary release their oxygen which passes through the wall and into the surrounding tissue. The tissue releases its waste products, like carbon dioxide, which passes through the wall and into the red blood cells.

Arteries and veins run parallel throughout the body with a web-like network of capillaries, embedded in tissue, connecting them. The arteries pass their oxygen-rich blood to the capillaries which allow the exchange of gases within the tissue. The capillaries then pass their waste-rich blood to the veins for transport back to the heart.

2.2 Blood System

2.2.1 Blood Definition

Blood is a liquid that flows within blood vessels. It is constantly in motion as the heart pumps blood through arteries to the different organs and cells of the body.

The blood is propelled back to the heart in the veins. When muscles contract, they squeeze the veins and allow the blood to be pushed back to the heart.

Because it contains living cells, blood is alive. Red blood cells which containing hemoglobin and white blood cells that fight infection are responsible for nourishing and cleansing the body.

Vitamins and Minerals keep the blood healthy. The blood cells have a definite life cycle, just as all living organisms do. Approximately 55 percent of blood is plasma, a straw-colored clear liquid. The liquid plasma carries the solid cells and the platelets which help blood clot .

Blood performs many important functions within the body including:

- Supply of oxygen to tissues by hemoglobin included in red blood cells.
- Supply of nutrients such as glucose, amino acids, and fatty acids.
- Removal of waste such as carbon dioxide, urea, and lactic acid.
- Immunological functions, including circulation of white blood cells, and detection of foreign material by antibodies.
- Coagulation, which is one part of the body's self-repair mechanism.
- Messenger functions, including the transport of hormones and the signaling of tissue damage.
- Regulation of body pH.

2.2.2 Red Blood Cells

Also called **erythrocyte**, it's a type of blood cell that is made in the bone marrow and release into the bloodstream after they fully mature, which takes about seven days. RBCs contain enormous amounts of a protein called hemoglobin, each red blood cell contains between 200 and 300 hemoglobin molecules which bind with oxygen as oxygen molecules enter blood vessels in the lungs. Hemoglobin is also responsible for the characteristic red color of blood. which carries oxygen from the lungs to all parts of the body **[9]** .

RBCs are microscopic and have the shape of a flat disk or doughnut, which is round with an indentation in the center as shown in **Figure (2.3)** , but it isn’t hollow. RBCs don’t have a nucleus like white blood cells, allowing them to change shape and move throughout the body easier. And they have a diameter of about 6 micrometers their small size allows them to squeeze through even the smallest human blood vessels.

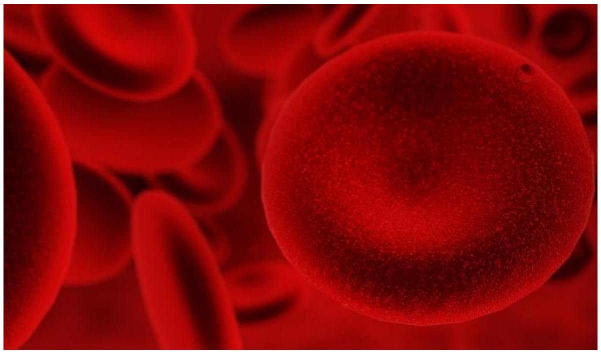


Figure (2.3): Surface view of RBC **[10] .**

RBCs have a limited lifespan because they don't have a center membrane (nucleus). When a red blood cell travels through the blood vessels, it uses up its energy supply and only survives an average of 100-120 days. the blood appears red because red blood cells make up (40-45)% of the blood's volume.

RBCs are derived from stem cells in red bone marrow. New red blood cell production, also called erythropoiesis, is triggered by low levels of oxygen in the blood. Low oxygen levels can occur for various reasons including blood loss, presence in high altitude, exercise, bone marrow damage, and low hemoglobin levels. when the kidneys detect low oxygen levels, they produce and release a hormone called erythropoietin. Erythropoietin stimulates the production of red blood cells by red bone marrow. As more red blood cells enter blood circulation, oxygen levels in the blood and tissues increase. When the kidneys sense the increase in oxygen levels in the blood, they slow the release of erythropoietin. As a result, red blood cell production decreases.

Function of red blood cells:

RBCs and it's hemoglobin are responsible for transporting oxygen from the lungs to the body's tissues **[9]** . The tissues produce energy with the oxygen and release a waste, identified as carbon dioxide. RBCs take the carbon dioxide waste to the lungs to exhale. The mammalian red cell is further adapted by lacking a nucleus, the amount of oxygen required by the cell for its own metabolism is thus very low, and most oxygen carried can be freed into the tissues. The biconcave shape of the cell allows oxygen exchange at a constant rate over the largest possible area.

Normal red blood cell count:

The number of red cells and the amount of hemoglobin vary among different individuals and under different conditions At birth the red cell count is high, it falls shortly after birth and gradually rises to the adult level at puberty.

The normal red blood cell count ranges (million red blood cells per microliter of blood.) are as follows **[11]** .

- Men: 4.7 - 6.1.
- Women: 4.2 - 5.4.
- Children: 4.0 - 5.5.
- New born: 4.8 - 7.1

If the count is outside of these ranges, it is either too high or too low will cause several diseases, such as anemia, polycythaemia and leukemia.

2.2.3 White Blood Cells

White blood cells, also known as leukocytes, are responsible for protecting the body from infection. As part of the immune system, white blood cells circulate in the blood and respond to injury or illness **[12]** . There are several types of WBCs as shown in **Figure (2.4)** .

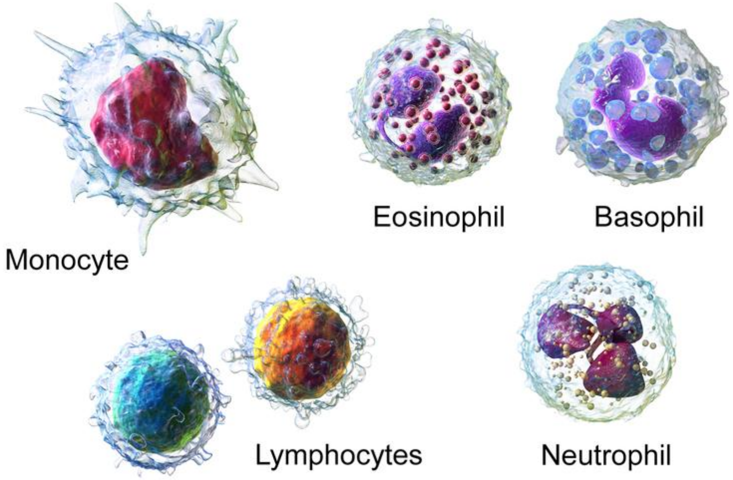


Figure (2.4): Different type cells of the human immune system **[12]** .

2.2.2 Platelets

These tiny fragments of cells are crucial in helping your blood to clot. If your platelet level is very low then you may suffer a lot from bruising and bleeding.

Figure (2.5): The picture illustrates platelets**.**

2.3 Hemoglobin and Anemia

Hemoglobin is a protein found in erythrocytes (red blood cells) that enables them to carry oxygen. Most oxygen that is carried within the blood is bound to hemoglobin. Hemoglobin is a composite molecule made of a combination of iron and the protein globin. Globin consists of four polypeptide chains: two alpha chains (alpha 1, alpha 2) and two beta chains (beta 1, beta 2), which bind a red ringlike heme group. Each heme group bears an iron ion (Fe^{+2}) set like a jewel in its center as shown in **Figure (2.6) [13]** .

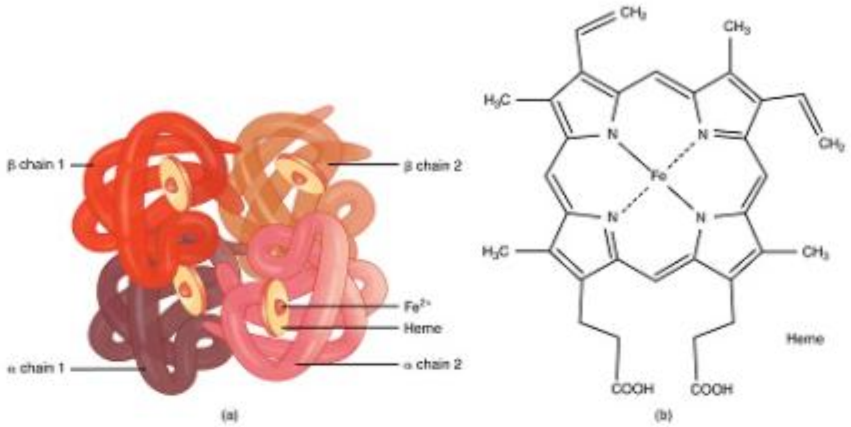


Figure (2.6): Hemoglobin molecule structure **[13]** .

Hemoglobin Functions:

Transport of Respiration Gases: This is the main function of hemoglobin. Hemoglobin can translate:

- Oxygen from lung to tissue: The oxygen is binds with hemoglobin, this physiology process called oxygenation. The iron stile as ferrous (Fe^{+2}) forming oxyhemoglobin. The oxygen is very important to metabolism process
- Carbon dioxide from tissue to lung: The carbon dioxide is binds with hemoglobin formatting carboxyhemoglobin. The CO2 is metabolism main waste product.
- Buffer action: Hemoglobin of RBC are regulate hydrogen ion concentration, since hemoglobin is good buffer.

Anemia is a global health problem: the World Health Organization estimates that a quarter of the world's population has to deal with anemia problems. Which is defined as the decrease in red cells in the blood or as a decrease in the normal concentration of hemoglobin (Hb), as shown in **Table (2.1)**. Consequently, it reduces the ability of the blood to transport oxygen. It is mainly caused by nutritional factors, infectious diseases or genetic factors. Severe anemia can compromise the availability of oxygen supplied to the cells and cause damage to vital organs.

Table (2.1): Normal range of the hemoglobin concentration **[14]** .

Age	Hb concentration
Newborns	17 to 22 gm/dL.
One week	15 to 20 gm/dL
One month	11 to 15 gm/dL
Children	11 to 13 gm/dL
Adult males	14 to 18 gm/dL
Adult women	12 to 16 gm/dL
Men after middle age	12.4 to 14.9 gm/dL
Women after middle age	11.7 to 13.8 gm/dL

Signs and symptoms of anemia:

- Fatigue.
- Weakness.
- Pale or yellowish skin.
- Irregular heartbeats.
- Shortness of breath.
- Dizziness or lightheadedness.
- Chest pain.
- Cold hands and feet.
- Headaches.

Anemia can cause a number of complications, including the following:

- Lasting fatigue leading to diminished productivity.
- Weakened immune system.
- Fast or irregular heartbeat.
- Heart failure.
- Problems during pregnancy, including fatigue, premature labor and problems with fetal development.
- Increased risk of postpartum depression.

2.4 Finger

Fingers are essential for completing everyday tasks. Fingers are one of the most used appendages, and the most delicate, so they are prone to injury. Finger injuries have the potential to slow down anyone.

Fingers have a complex anatomy. Each finger has 3 phalanges (bones) and 3 hinged joints; the thumb has two of each. Ligaments connect finger bones and help keep them in place. Tendons connect muscles to bones. Finger movement is controlled by muscles in the forearms that pull on finger tendons, as shown in **Figure (2.7) [15]** .

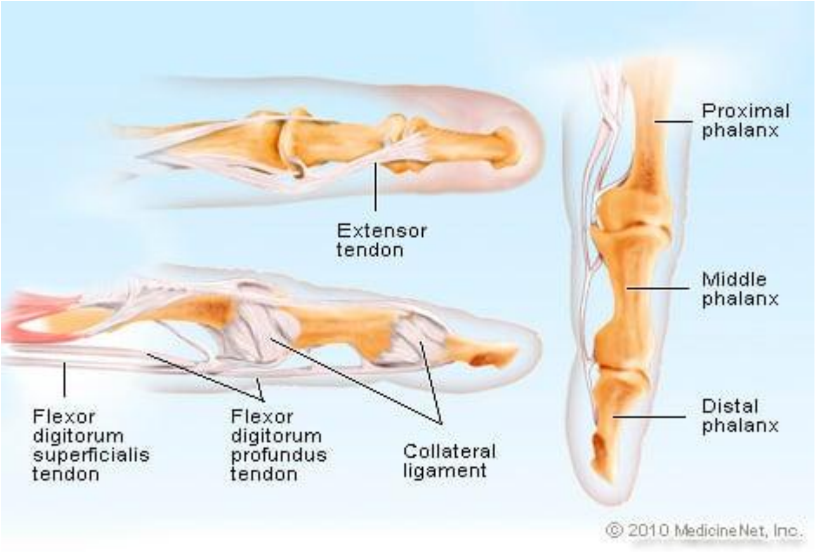


Figure (2.7): Illustration picture of finger Structures (Finger Anatomy) **[15]** .

After getting acquainted with some important information regarding the body, the circulatory system, its organs, blood, what is meant by hemoglobin, and anemia, we move on to chapter three to taking a glimpse of some methods, laws, and equations that help in designing system.

Chapter Three

Theoretical Background

3.1 Introduction

3.2 Complete Blood Count (CBC)

3.2 Spectrophotometry

3.3 Beer-Lambert law and Light Absorption

3.1 Introduction:

optical spectroscopy in the ultraviolet and visible light range (UV/VIS) is widely applied in almost all market segments and workplaces in research, production and quality control for the classification and study of substances. UV/VIS spectroscopy is based on the absorption of light by a sample. Depending on the amount of light and its wavelength absorbed by the sample, valuable information can be obtained, such as the purity of the sample. Moreover, the amount of absorbed light is related to the amount of sample, and thus, quantitative analysis is possible by optical spectroscopy.

In physical terms, light is a kind of energy propagating into space at a very high speed. More specifically, light is understood as an electromagnetic wave travelling into space – it is radiant energy. The energy of light oscillates periodically between a minimum and a maximum as a function of time – like a wave. The distance between two maxima or two minima, respectively of the electromagnetic wave is defined as the wavelength, given in nanometer (nm) as in the **Figure (3.1)** .

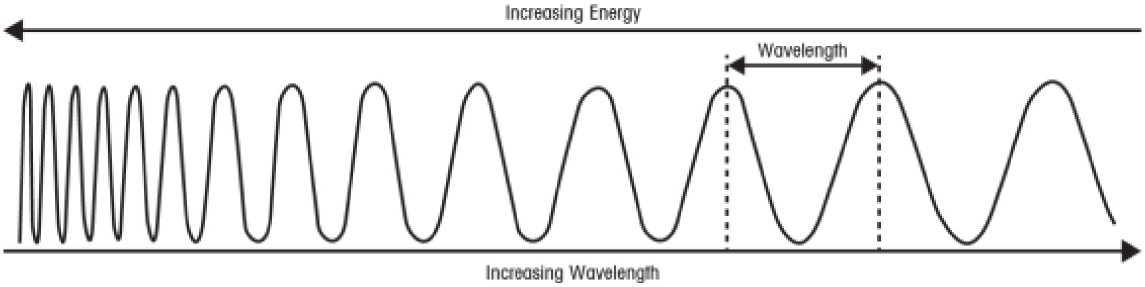


Figure (3.1): The energy of an electromagnetic wave increases with decreasing wavelength and vice versa **[16]** .

Each color has a specific wavelength, Thus, the different components of light are characterized by a specific wavelength. The sum of all components i.e. of all wavelengths, is called a spectrum. More specifically, a spectrum represents a distribution of radiant energy. For instance, the electromagnetic spectrum of visible light ranges from approximately 390 nm up to approximately 780 nm as shown in **Figure (3.2) [16]** .

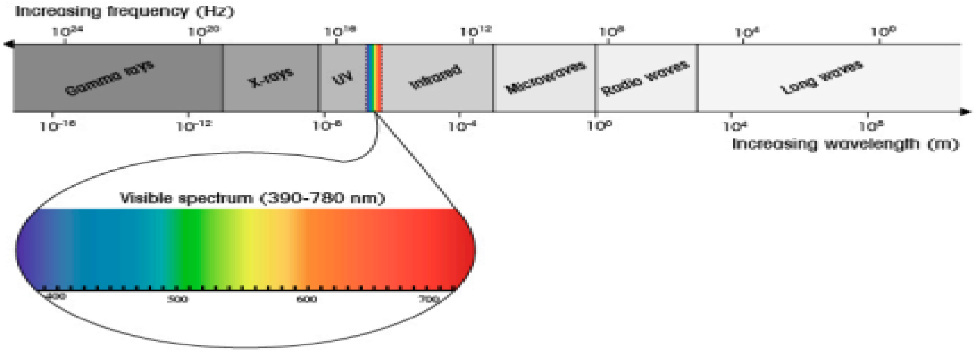


Figure (3.2): The visible spectrum (390-780 nm) represents only a small portion of the whole electromagnetic spectrum **[16]** .

UV/VIS spectroscopy has effectively been used in medical science for the routine analysis of blood and urine samples. The spectral differences between healthy blood and diseased blood can easily be compared.

Quantitation of blood hemoglobin has been a key diagnostic parameter for various diseases such as anemia, polycythemia and dehydration.

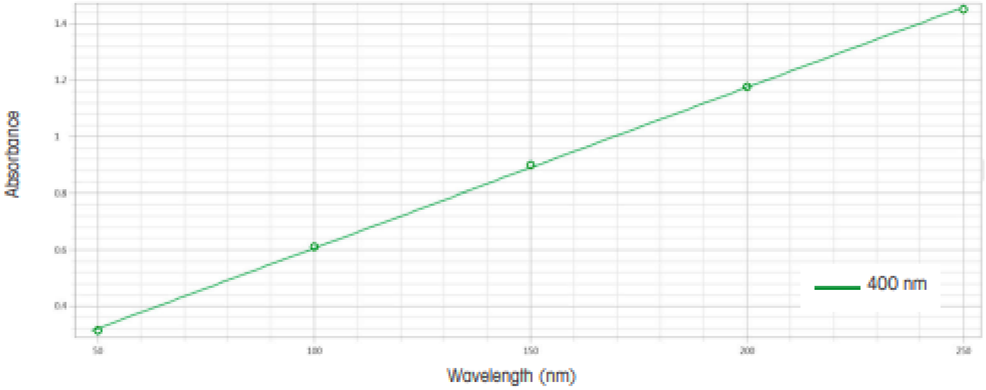


Figure (3.3): Standard curve with freshly prepared hemoglobin **[16]** .

3.2 Complete Blood Count (CBC)

A complete blood count (CBC), also known as a full blood count (FBC), is a set of medical laboratory tests that provide information about the cells in a person's blood. The CBC indicates the counts of white blood cells, red blood cells and platelets, the concentration of hemoglobin, and the hematocrit (the volume percentage of red blood cells). The red blood cell indices, which indicate the average size and hemoglobin content of red blood cells, are also reported, and a white blood cell differential, which counts the different types of white blood cells, may be included . Red blood cell indices can provide information about the cause of a person's anemia such as iron deficiency and vitamin B12 deficiency.

The CBC is performed using basic laboratory equipment or an automated hematology analyzer, which counts cells and collects information on their size and structure. The concentration of hemoglobin is measured, and the red blood cell indices are calculated from measurements of red blood cells and hemoglobin.

Two other measurements are calculated from the red blood cell count, the hemoglobin concentration, and the hematocrit: the mean corpuscular hemoglobin and the mean corpuscular hemoglobin concentration. These parameters describe the hemoglobin content of each red blood cell. The MCH and MCHC can be confusing; in essence the MCH is a measure of the average amount of hemoglobin per red blood cell. The MCHC gives the average proportion of the cell that is hemoglobin. The MCH does not take into account the size of the red blood cells whereas the MCHC does. Collectively, the MCV, MCH, and MCHC are referred to as the red blood cell indices. Changes in these indices are visible on the blood smear: red blood cells that are abnormally large or small can be identified by comparison to the sizes of white blood cells, and cells with a low hemoglobin concentration appear pale. Another parameter is calculated from the initial measurements of red blood cells: the red blood cell distribution width or RDW, which reflects the degree of variation in the cells' size. An abnormally low hemoglobin, hematocrit, or red blood cell count indicates anemia **[17]** .

3.3 Spectrophotometry

Spectrophotometry is a standard and inexpensive technique to measure light absorption or the amount of chemicals in a solution. It uses a light beam which passes through the sample, and each compound in the solution absorbs or transmits light over a certain wavelength.

Spectrometry is measured by a spectrophotometer; an instrument that is made up of two instruments – a spectrometer and a photometer. The spectrometer produces the light of the wavelength and the photometer measures the intensity of light by measuring the amount of light that passes through the sample.

In addition to those two components, spectrophotometers consist of a light source, a monochromator, a sample chamber containing a cuvette, a detector (such as a photomultiplier tube or photodiode) to detect the transmitted light, a digital display and a data analysis software package as in the **Figure(3.4) [18]** .

- **Uses of a Spectrophotometer :**
  1. Pharmaceutical Production .
  2. Water Analysis .

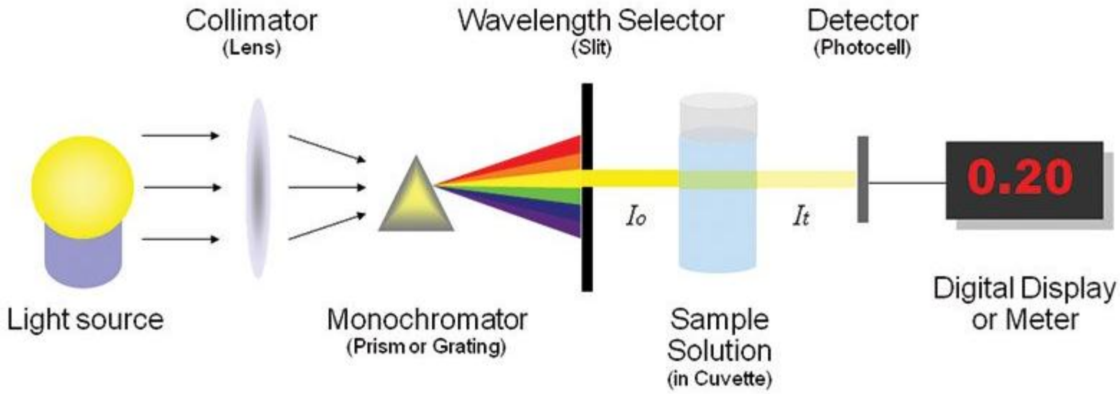


Figure (3.4): component of spectrophotometer **[19]** .

Spectrophotometry is the basis for all oximetry. The atoms of all molecules vibrate in specific patterns for each unique substance. As light passes through a substance, the frequencies of light similar to the vibrational frequencies of the substance are absorbed. A spectrophotometer measures the intensity of light transmitted through a particular substance at particular wavelengths. The fraction of light absorbed at a specific wavelength is determined by the absorptivity, or extinction coefficient, of the substance. The extinction coefficient of a substance can be graphed at various wavelengths as a spectrum. This spectrum is unique for every substance.

The objective of the photometric devices described the non-invasive continuous measurement of heart circulation patterns and light absorbent blood components in the blood of the human finger. The arteries contain more blood during the systolic phase of the heart than during the diastolic phase, due to an increased diameter of the arteries during the systolic phase.

This effect occurs only in arteries but normally not in veins. For this reason the absorbance of light in tissues with arteries increases during systole because the amount of hemoglobin (absorber) is higher and the light passes through a longer optical path length in the arteries. These intensity changes are called PPG-waves.

The time varying part allows the differentiation between the absorbance due to venous blood and bloodless tissue (DC part) such as (skin, muscle and bone) and that due to the pulsatile component of the total absorbance

(AC part), as shown in **Figure (3.5)** . Upon interaction with the tissue the transmitted light is detected non-invasively by photo diodes.

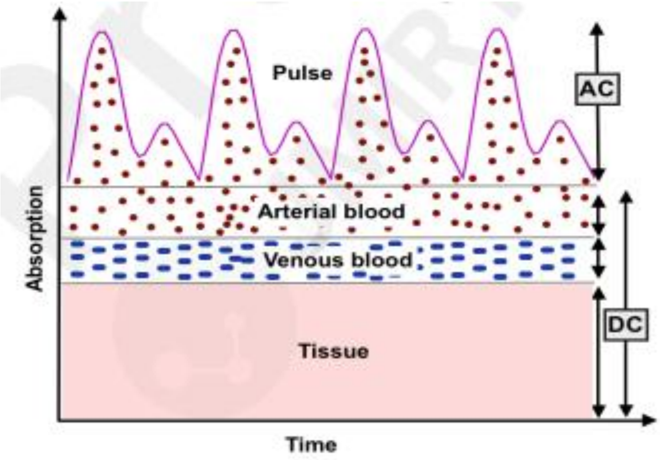


Figure (3.5): Light absorption changes for pulse, arterial and venous blood, and living tissue **[20]** .

A photo detector is a device that converts light intensity into an electric current. A given intensity of light transmitted through a substance produces an electric current proportional to the intensity. By measuring the intensity of incident light on a substance (I_O) and measuring the intensity of light transmitted through the substance (I), the transmittance (T) of the substance can be calculated as shown in **Equation (3.1)** :

$$T = \frac{I}{I\,O} \text{…………..} \ (3.1)$$

Because each molecule absorbs an equal portion of light, the absorbance of light through a substance is linearly related to the concentration of substance present. From the measured transmittance (T), the absorbance (A) can be calculated from as shown in **Equation (3.2)** :

$$A = 2 - log(\%T) \text{…………..} \ (3.2)$$

Then Beer's law can now be used to find the amount of substance in a solution.

3.4 Beer-Lambert Law

The Beer-Lambert law describes the reduction of light, which is travelling through a homogeneous medium; contain an absorbing substance as shown in **Equation (3.3)** . Also this law allow to find the concentration of a single substance or more than one absorbing substance.

$$A=\mathcal{E}cl \ldots\ldots\ldots\ldots\ldots (3.3)$$

Where :
A : is the absorbance .
Ɛ : is the molar absorption coefficient .
c : is the molar concentration .
l : is the optical path length .

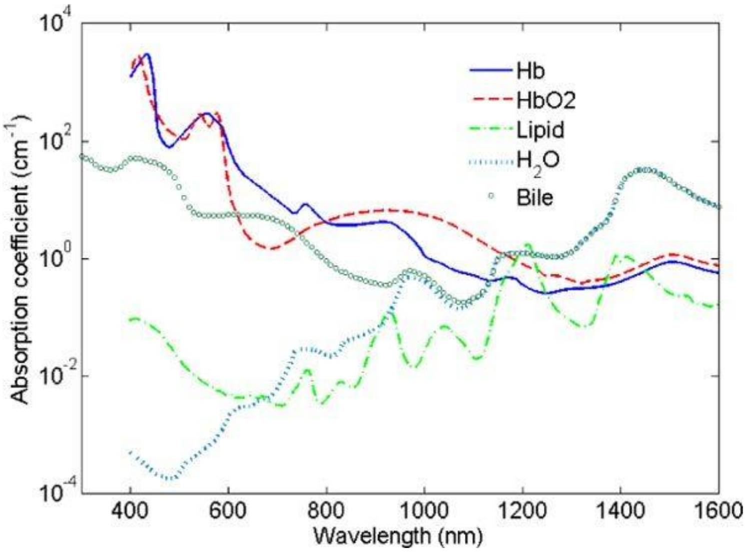


Figure (3.6) : Optical absorption coefficients of oxyhemoglobin and reduced hemoglobin and water **[21]** .

Also the unscattered absorbance A is defined as the negative natural logarithm of the transmittance ratio (I to I0) as shown in **Equation (3.4)** :

$$A= -\log (I/Io) \ldots\ldots\ldots\ldots\ldots (3.4)$$

Where :

Io : intensity of light entering the sample .
I : intensity of light leaving the sample .

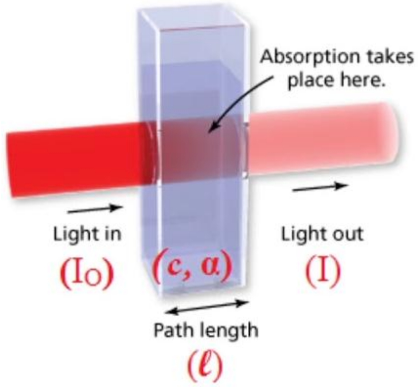


Figure (3.7) : Lambert's law states that that absorption is proportional to the light path length **[16]** .

The transmissive or reflective process captures the properties of a living tissue non-invasively.

The variation of this transmitted or reflected light depends on the shape, volume, refractive index of Hb, and angular distribution of scattered light, which characterizes the absorption properties of blood and tissue. Analyzing these changes in optical scattering properties in tissues, we can build a non-invasive solution for Hb estimation.

Hemoglobin has different forms in the blood. such as oxyhemoglobin, reduced hemoglobin, carboxyhemoglobin, and methemoglobin. Oxyhemoglobin (HbO2) and reduced hemoglobin (Hb) are main forms that are available in the blood. The other forms are available only in traces. Oxyhemoglobin is mainly available in arteries and the reduced hemoglobin is available in veins, but in capillaries, both the forms are available

The oxyhemoglobin and reduced hemoglobin have a different absorption of light at different wavelengths. **Figure (3.8)** it shows the variation in molar extinction coefficient of light (µa) of the two hemoglobin forms with wavelength variation. During the measurement of hemoglobin the absorption should not be dependent on the oxygen saturation. That means that the measurement is only practicable at so called isobestic points where the extinction coefficients of Hb and HbO2 are identical. One such point is known to exist around 810nm **[6]** .

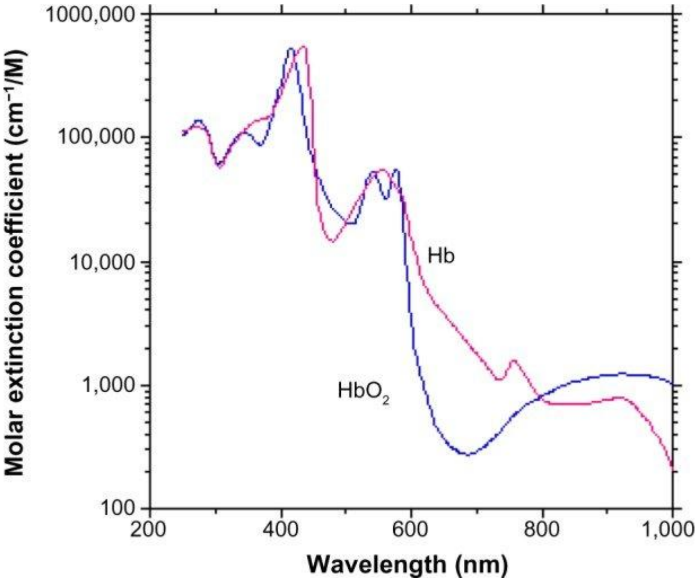


Figure (3.8): Molar extinction coefficient of light of oxyhemoglobin and reduced hemoglobin **[22]** .

Suitable wavelengths were selected for the analyses of relative hemoglobin concentration change. The principle of measurement is based on the fact of a substantial absorption/transmission difference of light in red and near infrared region between oxygenated [HbO2] and reduced hemoglobin [HHb]. HHb is optically much denser to the red light than HbO2 . whereas the reverse is true in the near infrared region as shown in **Figure (3.9)** .

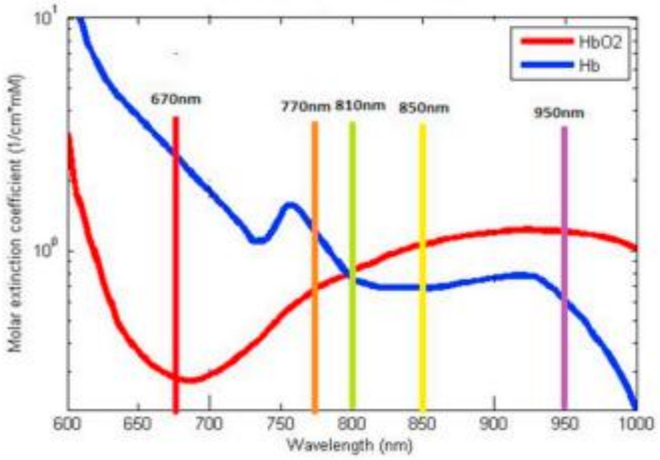


Figure (3.9): Hemoglobin light absorption graph **[23]** .

Two wavelengths (λ = 650 nm and 940 nm). The two equations listed below were used to estimate oxy-hemoglobin and deoxy-hemoglobin :

$$\mathbf{PPG\_\ Ratio_{650} = \varepsilon Hb^{650} * Hb * L + \varepsilon HbO_2^{650} * HbO_2 * L \quad \ldots\ldots\ (3.5)}$$

$$\mathbf{PPG\ \_Ratio_{940} = \varepsilon Hb^{940} * Hb * L + \varepsilon HbO_2^{940} * HbO_2 * L \quad \ldots\ldots\ (3.4)}$$

Where :

PPG_Ratio: the ratio of AC voltage of the PPG to DC voltage of the PPG for each wavelength.

εHb^{λ} : molar extinction coefficient for deoxy-hemoglobin .

$\varepsilon HbO_2{}^{\lambda}$: the molar extinction coefficient for oxy-hemoglobin .

Hb & HbO_2 : the concentration of oxyhemoglobin and deoxy-hemoglobin .

The AC component of a PPG signal is the difference between its Peak (maximum) and Valley (minimum) voltages, whereas the DC component is the Valley voltage.

Formula to Calculate Total Hemoglobin for two wavelengths using **Equations (3.5) and (3.6).**

$$\begin{bmatrix} PPG\_\text{Ratio650} \\ \text{PPG \_Ratio940} \end{bmatrix} = \begin{bmatrix} \varepsilon\text{Hb650} & \varepsilon\text{HbO2 650} \\ \varepsilon\text{Hb940} & \varepsilon\text{HbO2 940} \end{bmatrix} * \begin{bmatrix} Hb \\ HbO2 \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots.. (3.7)$$

The unknown oxy-hemoglobin and deoxy-hemoglobin are calculated by rearranging the **Equation (3.7)**:

$$\begin{bmatrix} Hb \\ HbO2 \end{bmatrix} = \begin{bmatrix} PPG\_\text{Ratio650} \\ \text{PPG \_Ratio940} \end{bmatrix} * inv \begin{bmatrix} \varepsilon\text{Hb650} & \varepsilon\text{HbO2 650} \\ \varepsilon\text{Hb940} & \varepsilon\text{HbO2 940} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots.. (3.8)$$

From **Equation (3.8)**, total hemoglobin is calculated by adding the concentration of oxyhemoglobin and deoxy-hemoglobin.

$$\text{THb} = \text{Hb} + \text{HbO}_2 \quad \ldots\ldots\ldots\ldots\ldots.. (3.9)$$

Equation (3.9) indicates the concentration of total hemoglobin in Moles per liter which is converted into grams per deciliter.

Based on research and experiments, the value of the Molar Extinction Coefficient for Hemoglobin was found **[24]** , and it is as follows:

$$\varepsilon\text{Hb650} = 3750 \qquad \varepsilon\text{HbO2 650} = 368$$
$$\varepsilon\text{Hb940} = 693 \qquad \varepsilon\text{HbO2 940} = 1214$$

After rearranging the equations, we get:

$$\text{Hb} = 2.8249\text{E-4} * \text{PPG 650} - 8.563\text{E-5} * \text{PPG 940} \quad \ldots\ldots\ldots\ldots\ldots.. (3.10)$$

$$\text{HbO}_2 = \frac{PPG\,940 - 0.1848 * PPG\,650}{1145.9936} \quad \ldots\ldots\ldots\ldots\ldots.. (3.11)$$

These equations are programmed using the programs inside the Arduino so that the Arduino processes the signal arriving through it.

In the next chapter, we will learn about the parts used in the design of the system and how to connect them.

Chapter Four

Project System Design

4.1 Introduction

Continuously measuring the concentration of hemoglobin in the blood without the need to visit clinics and hospitals and pay high costs is important, and this is what we seek to achieve through this project.

This chapter explains the parts and parts needed to design and build this project, in addition to the necessary software programs as well.

4.2 General Block Diagram of the Project

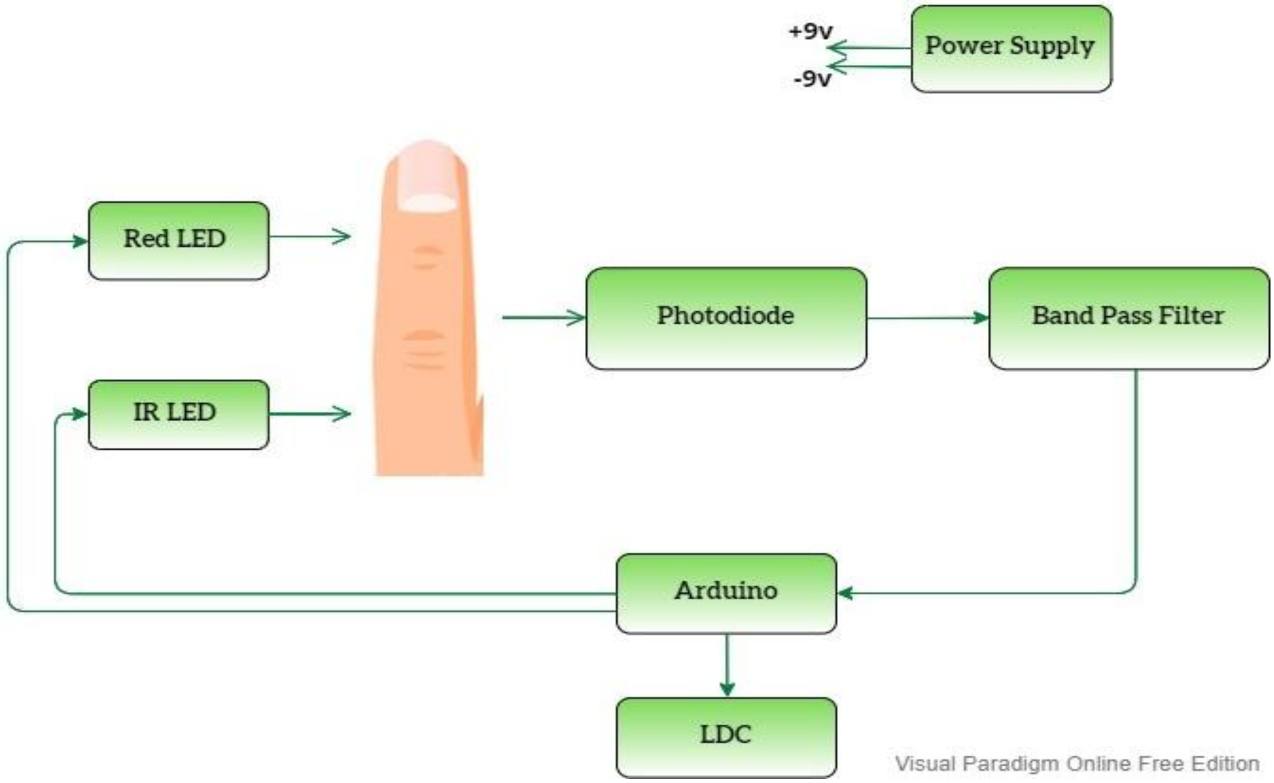


Figure (4.1) : General Block Diagram .

4.3 Hardware Components of the Project

Through this section of chapter all hardware components used in the project are discussed, so that features and specifications are discussed.

4.3.1 LEDs

Light-emitting diode (LED) is a semiconductor device that emits light when an electric current is passed through it. Light is produced when the particles that carry the current (known as electrons and holes) combine together within the semiconductor material.

The photon energy determines the wavelength of the emitted light, and hence its color. Different semiconductor materials with different bandgaps produce different colors of light.

- **Red LED : 640 – 700 nm .**
  We use LUXEON 3W Red light LED to emit 650nm wavelength . To ensure that the photodiode emits a specified wavelength, the specified current must be supplied (700mA) **(Appendix A)** . The Red LED driving circuit shown in **Figure (4.2)** :

The resistor R1 calculate by **Equation (4.1)** :

$$\boldsymbol{R1} = \frac{\boldsymbol{VDD - VLED}}{\boldsymbol{I\ LED}} \quad \text{..............} \ \textbf{(4.1)}$$

$$\boldsymbol{R1} = \frac{\mathbf{5 - 2.2}}{\boldsymbol{700mA}} = \mathbf{4}\ \Omega$$

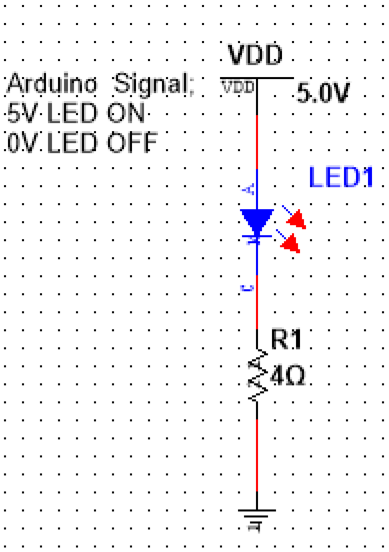


Figure (4.2) : Red LED driving circuit.

- **Infrared LED : 800 – 980 nm .**

We use 6070 SMD 3W 940nm Infrared IR LED. To ensure that the photodiode emits a specified wavelength, the specified current must be supplied (700mA) **(Appendix B)** . The IR LED driving circuit shown in **Figure (4.3)** :

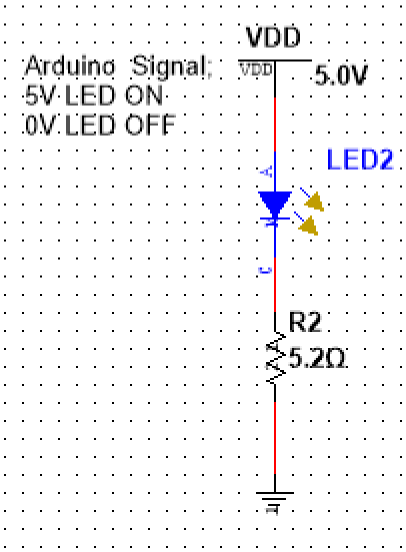


Figure (4.3) : IR LED driving circuit .

The resistor R2 calculate by **Equation (4.1)** :

$$\boldsymbol{R2} = \frac{\boldsymbol{VDD-VLED}}{\boldsymbol{I\ LED}} \quad \text{..............} \ \textbf{(4.1)}$$

$$\boldsymbol{R2} = \frac{\mathbf{5-1.3}}{\mathbf{700}\boldsymbol{mA}} = \mathbf{5.2}\ \Omega$$

The microcontroller generate a square signal for both LEDs with a difference in operating time as shown in **Figure (4.4)** :

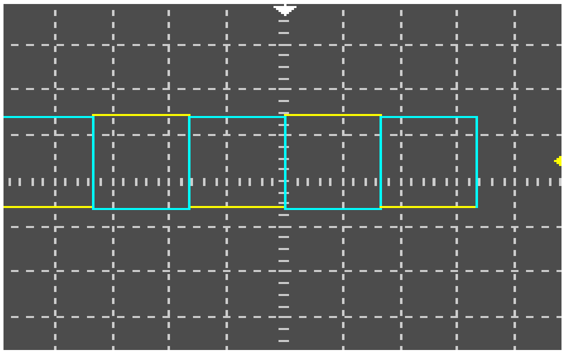


Figure (4.4) : Microcontroller Signal .

4.3.2 Detectors

Detector is any device that receives a signal or stimulus (as heat or pressure or light or motion etc) .

The main forms of light detectors used with optical systems are photoconductors (photoresistors), photovoltaic devices (photocells) and photodiodes.

- Photoconductive devices (photoresistors) they convert changes in incident light into changes in resistance, with the resistance reducing according to the intensity of light to which they are exposed.

- Photovoltaic devices (photocells) they are also commonly known as solar cells when a number of them are used in an array as a means of generating energy from sunlight. Their basic mode of operation is to generate an output voltage whose magnitude is a function of the magnitude of the incident light that they are exposed to.

- Photodiodes is a PN-junction diode that consumes light energy to produce an electric current. These diodes are particularly designed to work in reverse bias conditions, it means that the P-side of the photodiode is associated with the negative terminal of the battery, and the n-side is connected to the positive terminal of the battery. This diode is very sensitive to light so when light falls on the diode it easily changes light into an electric current.

- So we use OPT101 as a detector for red light and infrared light **(Appendix C)** . **Figure (4.5)** below shows the current to voltage converter circuit for each photodiode :

  - **OPT101 :**

    It is a monolithic photodiode with on-chip transimpedance amplifier. The integrated combination of photodiode and transimpedance amplifier on a single chip. So it doesn't need current to voltage converter circuit .

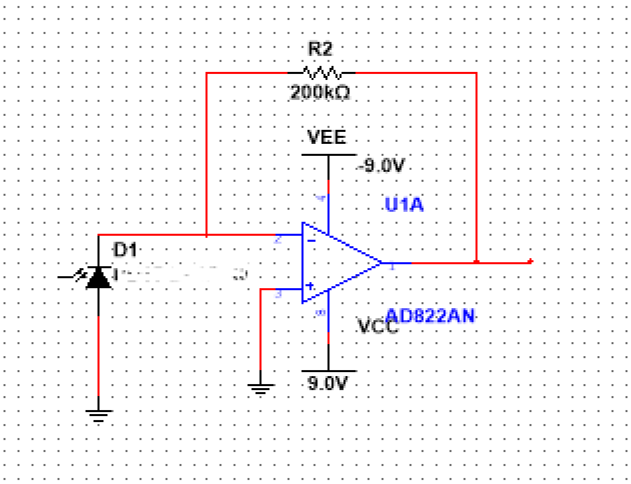


Figure (4.5) : Current to voltage converter circuit .

The maximum output voltage of the circuit is

Vmax = **I max** ∗ **R2**

Which, *R*2 =200kΩ.

Vmax = 5.4 V.

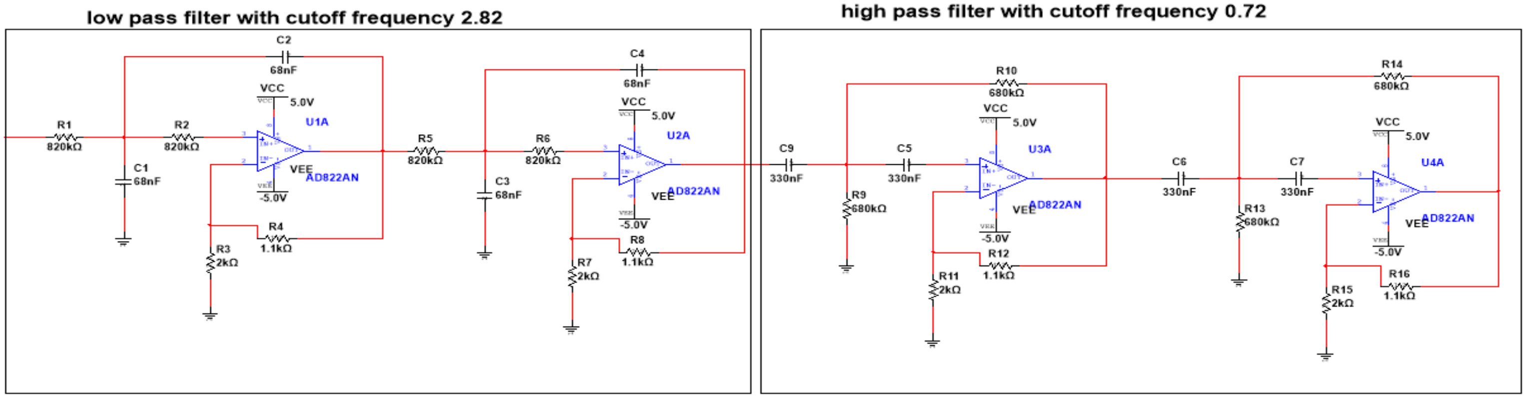
4.3.3 Band Pass Filter

The output of the current to voltage converter circuit is fed into a band pass filter.

The PPG signal is of an order of millivolts along with noise. Since the frequency of the human heart is around 1–2 Hz, the PPG signal was separated from noise using an active band pass filter (0.72 Hz to 2.82 Hz) with an appropriate gain.

The band pass filter is designed using a low pass filter and a high pass filter together, each 4th orders as shown in **Figure (4.6)** .

We used **AD822** OP-Amp in filter's design for several reasons, it's a rail-to-rail op-amp, with CMRR=80dB, and its input impedance =1013 with Offset voltage of 800 µV maximum. The input bias currents below 25 pA , 1.8 MHz unity-gain bandwidth and 3 V/µs slew rate,dual precision, used in a medical instrumentations applications **(Appendix D)**.


low pass filter with cutoff frequency 2.82

high pass filter with cutoff frequency 0.72

Figure (4.6) : Band pass filter.

A special case of the general Sallen-Key topology is the application of equal resistor values and equal capacitor values: R1 = R2 = R and C1 = C2 = C. The general transfer function changes to :

$$A(S) = \frac{A_0}{1 + WcRC(3 - A_0)S + (WcRC)^2 S^2}$$

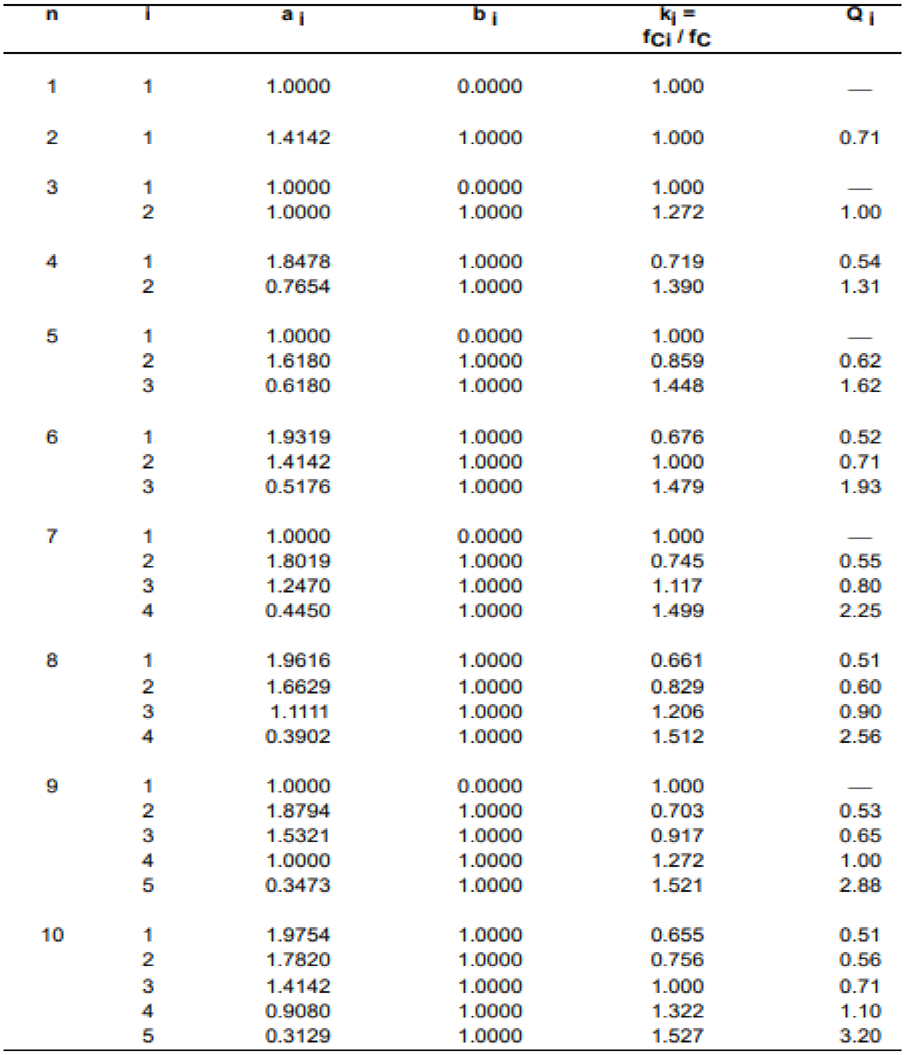
With

$$A_0 = 1 + \frac{R_4}{R3}$$

$$a1 = WcRC(3 - A_0)$$

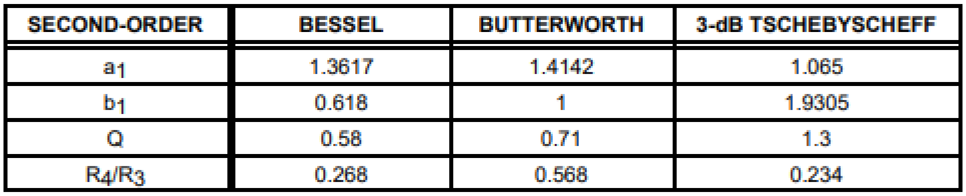
$$b1 = (WcRC)^2$$

Table (4.1): Butterworth Coefficients .



n	i	a_i	b_i	$k_i =$ f_{Ci} / f_C	Q_i
1	1	1.0000	0.0000	1.000	—
2	1	1.4142	1.0000	1.000	0.71
3	1	1.0000	0.0000	1.000	—
	2	1.0000	1.0000	1.272	1.00
4	1	1.8478	1.0000	0.719	0.54
	2	0.7654	1.0000	1.390	1.31
5	1	1.0000	0.0000	1.000	—
	2	1.6180	1.0000	0.859	0.62
	3	0.6180	1.0000	1.448	1.62
6	1	1.9319	1.0000	0.676	0.52
	2	1.4142	1.0000	1.000	0.71
	3	0.5176	1.0000	1.479	1.93
7	1	1.0000	0.0000	1.000	—
	2	1.8019	1.0000	0.745	0.55
	3	1.2470	1.0000	1.117	0.80
	4	0.4450	1.0000	1.499	2.25
8	1	1.9616	1.0000	0.661	0.51
	2	1.6629	1.0000	0.829	0.60
	3	1.1111	1.0000	1.206	0.90
	4	0.3902	1.0000	1.512	2.56
9	1	1.0000	0.0000	1.000	—
	2	1.8794	1.0000	0.703	0.53
	3	1.5321	1.0000	0.917	0.65
	4	1.0000	1.0000	1.272	1.00
	5	0.3473	1.0000	1.521	2.88
10	1	1.9754	1.0000	0.655	0.51
	2	1.7820	1.0000	0.756	0.56
	3	1.4142	1.0000	1.000	0.71
	4	0.9080	1.0000	1.322	1.10
	5	0.3129	1.0000	1.527	3.20

Table (4.2): Second-Order Filter Coefficients



SECOND-ORDER	BESSEL	BUTTERWORTH	3-dB TSCHEBYSCHEFF
a_1	1.3617	1.4142	1.065
b_1	0.618	1	1.9305
Q	0.58	0.71	1.3
R_4/R_3	0.268	0.568	0.234

- **Low Pass Pilter :**

  The low pass filter enable us to filter out unwanted signals. The low pass filter will essentially allow to cutoff signals at a frequency of 2.82 Hz, while attenuate any higher frequencies. After the low pass filter, the output fed to high pass filter.

  When solving equations

$$R = \frac{\sqrt{b1}}{2\pi f_c C}$$

$$Q = \frac{1}{3 - A_0}$$

Let C=68nF

$$R = \frac{\sqrt{1}}{2 * 3.14 * 2.82Hz * 68nF} = 830390.4297\Omega$$

By standard resistance value, R=820k Ω

$$A_0 = 1 + \frac{R_4}{R_3}$$

By **Table (4.2)** .

$\frac{R_4}{R_3} = 0.568$

$A_0 = 1 + 0.568 = 1.568$

$R_4 = 0.568 * R_3$ let $R_3 = 2K$

$$R_4 = 1.136K$$

By standard resistance value, $R_4 = 1.1K$

The first stage and the second stage are similar because the value of b1 is equal to b2 according to the **Table (4.1)** .

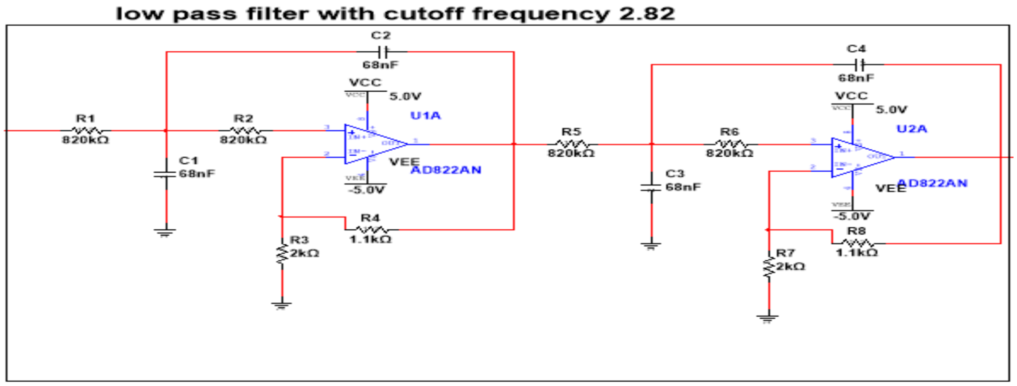


Figure (4.7): Sallen-key butterworth 4th order low pass filter

- **High Pass Filter :**
  The high pass filter allows us to filter out unwanted signals. The high-pass filter will essentially allow to cut off signals at a frequency of 0.72 Hz, while attenuating any lower frequencies. After the high pass filter, the output is fed to the Arduino.

  When solving equations

$$R = \frac{\sqrt{b1}}{2\pi f_c C}$$

$$Q = \frac{1}{3 - A_0}$$

Let C=330nF

$$R = \frac{\sqrt{1}}{2 * 3.14 * 0.72Hz * 330nF} = 670183.7912\Omega$$

By standard resistance value, R=680 k Ω

$$A_0 = 1 + \frac{R_{12}}{R_{11}}$$

By **Table 4.2**

$$\frac{R_{12}}{R_{11}} = 0.568$$

$$A_0 = 1 + 0.568 = 1.568$$

$R_{12} = 0.568 * R_3$ let $R_{11} = 2K$

$$R_{12} = 1.136K$$

By standard resistance value, $R_{12} = 1.1K$

The first stage and the second stage are similar because the value of b1 is equal to b2 according to the **Table(4.1)** .

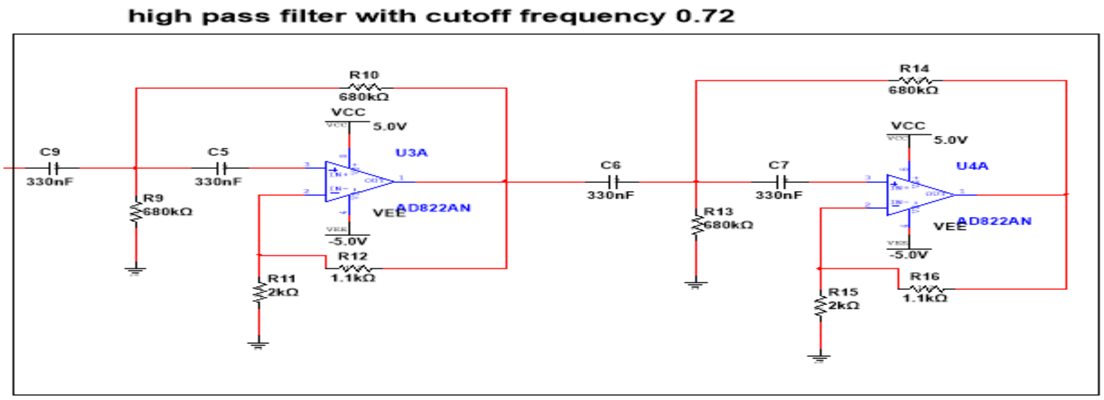


Figure (4.8): Sallen-key butterworth 4th order high pass filter.

4.3.4 Microcontroller

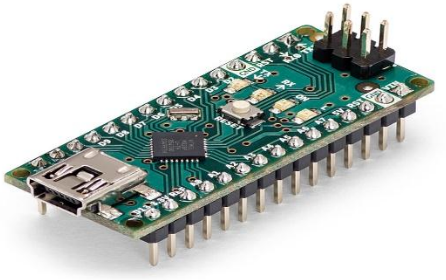
A microcontroller is an integrated circuit (IC) device used for controlling other portions of an electronic system, usually via a microprocessor unit (MPU), memory, and some peripherals. These devices are optimized for embedded applications that require both processing functionality and agile, responsive interaction with digital, analog, or electromechanical components.

- **Arduino :**

Arduino refers to an open-source electronics platform or board and the software used to program it. Arduino is designed to make electronics more accessible to artists, designers, hobbyists and ayone interested in creating interactive objects or environments. An Arduino board can be purchased pre-assembled or, because the hardware design is open source, built by hand. Either way, users can adapt the boards to their needs, as well as update and distribute their own versions.

They operate at 5 volts and each pin can provide or receive a maximum of 40 mA.

- **Arduino nano:**
  The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x). It has more or less the same functionality of the Arduino Duemilanove, but in a different package. It lacks only a DC power jack, and works with a Mini-B USB cable instead of a standard one.



4.3.5 LCD

LCD (Liquid Crystal Display) is a type of flat panel display which uses liquid crystals in its primary form of operation. LEDs have a large and varying set of use cases for consumers and businesses, as they can be commonly found in smartphones, televisions, computer monitors and instrument panels.

4.4 Power Supply

It is necessary to find an appropriate power source to feed the system by current and voltage required . As the system may be required to be portable a battery that has the following characteristics is required :

- Lightweight.
- Enough supply voltage.
- Enough supply current.

Table (4.2) : Approximation of a current consumption .

Elements	#	Approximation of a current consumption
Red LED Circuit	1	700 mA
IR LED Circuit	1	700 mA
Opt101 photodiode	1	120 uA
AD822	2	3.72 mA
4th Order LPF	1	5 mA
LM741	1	1.7 mA
LM7805	1	1 A
Arduino nano	1	19 mA
LCD (16*2)	1	200 mA
Total Current		≈ 2.63326 A

Thus, we used lithium Rechargeable battery USB charging 9v li-ion Square battery 5500mAH.

$$\# \text{ of hours} = \frac{5500}{2633.26} = 2 .$$

As we mentioned earlier that the appropriate voltage for most of the pieces is 5v , we used a voltage regulator (LM7805) to get this value **(Appendix E)** .

4.5 Project Circuit :

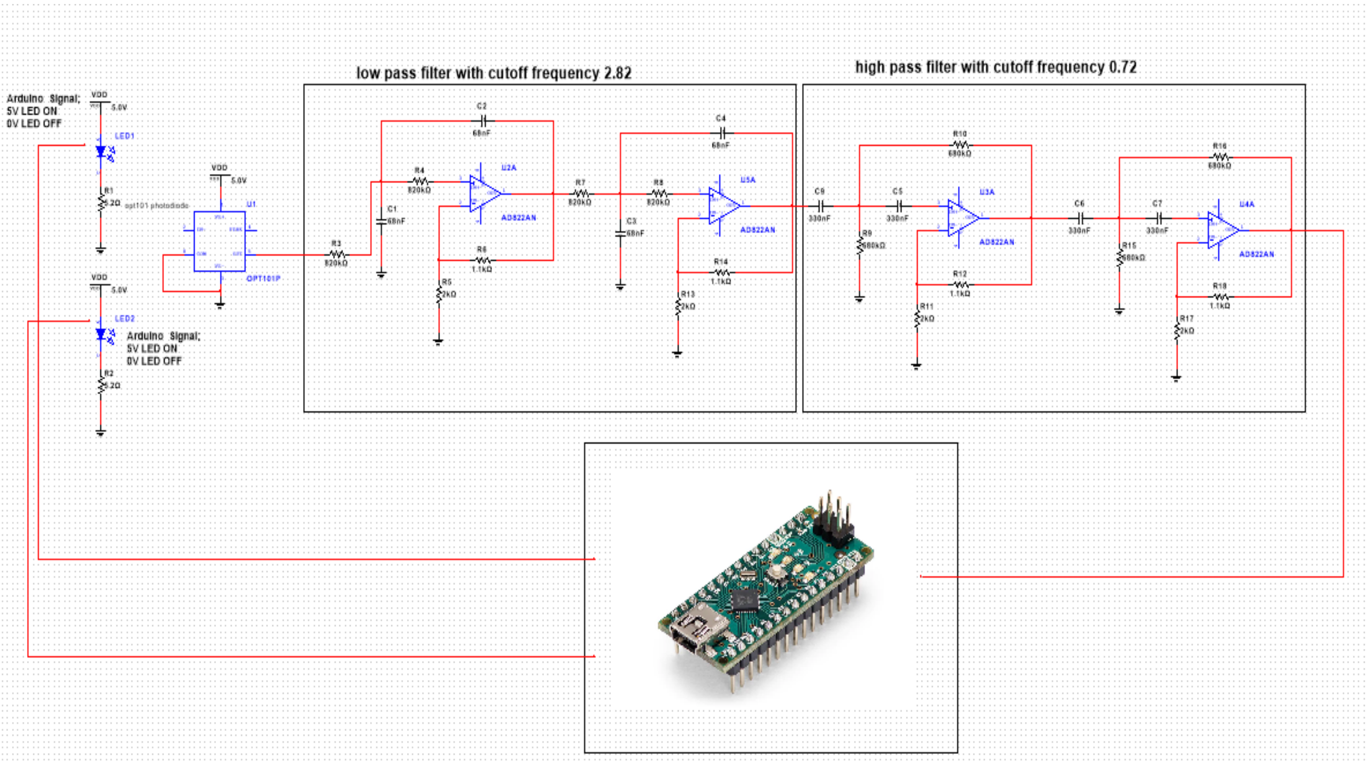


Figure (4.8) : Project Circuit .

After getting acquainted with the parts used in building the system, we will show in the fifth chapter how to connect them on the ground and the results we have reached.

5

Chapter Five

Implementation and Results

5.1 System Implementation .

5.2 System Software.

  5.2.1 Flowchart.

  5.2.2 System Programming.

5.3 Results of Hemoglobin Concentration .

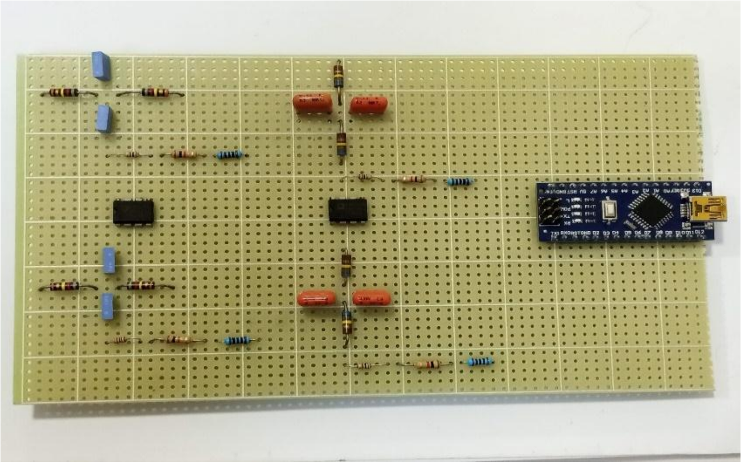
5.1 System Implementation

In this section , we will explain how we assembled the parts and built the project .

In the beginning, the LEDs were installed inside the probe, in addition to connecting it with the Arduino to operate them , and on the opposite side of the LEDs, the detector was installed as shown in **Figure(5.1)** .

Figure(5.1) : Probe Construction .

After that, the terminal of the detector is connected with the filter that is connected to the Arduino, as shown in **Figure(5.2)** , in order to process the signal in it and get the result based on the code inside it.



Figure(5.2) : Filter & Arduino .

5.2 System Software

5.2.1 Flowchart

The LCD and ADC is configured. The PPG is recorded for two wavelengths of LEDs (650 nm & 940 nm). Next, the peak and valley voltages of the PPG signal are detected for each wavelength. The PPG signal was plotted on the serial Monitor and saved for further offline analysis. The AC voltage (Max Voltage — Min Voltage) and DC voltage (Minimum Voltage) for each wavelength are calculated. Next, the PPG Ratio of AC voltage and DC voltage for each wavelength is calculated.

Total hemoglobin of the subject for two wavelengths is calculated using well known extinction coefficients of oxy-hemoglobin and deoxy-hemoglobin and the PPG ratio for two wavelengths. Finally, the total Hemoglobin level with two wavelengths using non-invasive methods is displayed. The flowchart depicting the details steps is shown in **Figure (5.3)** .

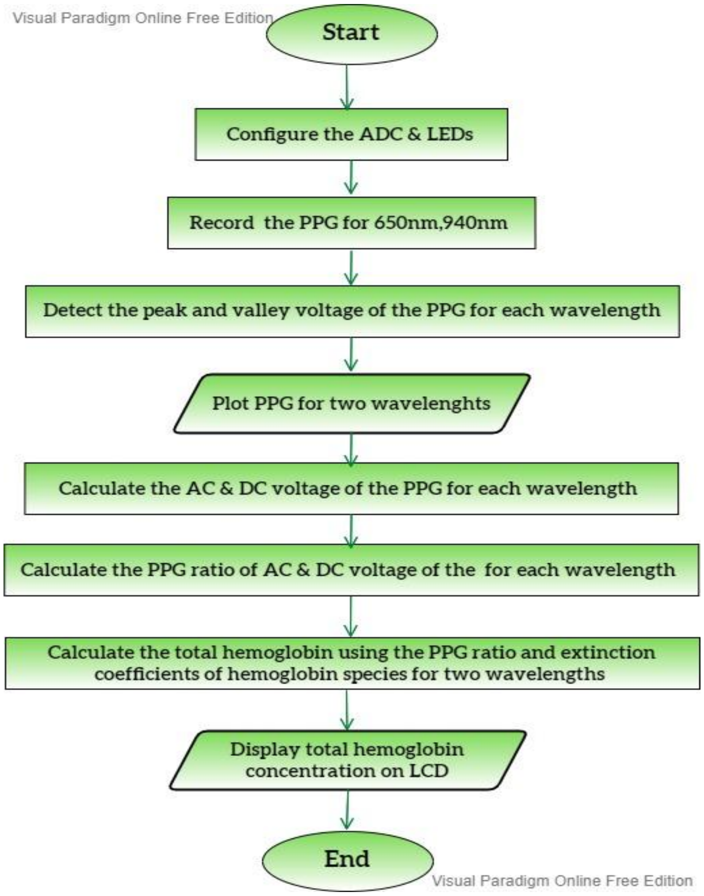


Figure (5.3): Flowchart for Hemoglobin estimation using two wavelengths PPG.

5.2.2 System Programming

LabVIEW (laboratory virtual instrument engineering workbench) also called virtual instrument of Vis, because their appearance and operation imitate physical instruments, such as oscilloscope and multimeters. LabVIEW contains a comprehensive set of tools for acquiring, analyzing, displaying, and storing data, as well tools to help your troubleshoot your cade.

In this project, LabVIEW used to control LEDs on and off time. at the same time, LabVIEW will acquire signals from detector , analysis signals and display result.

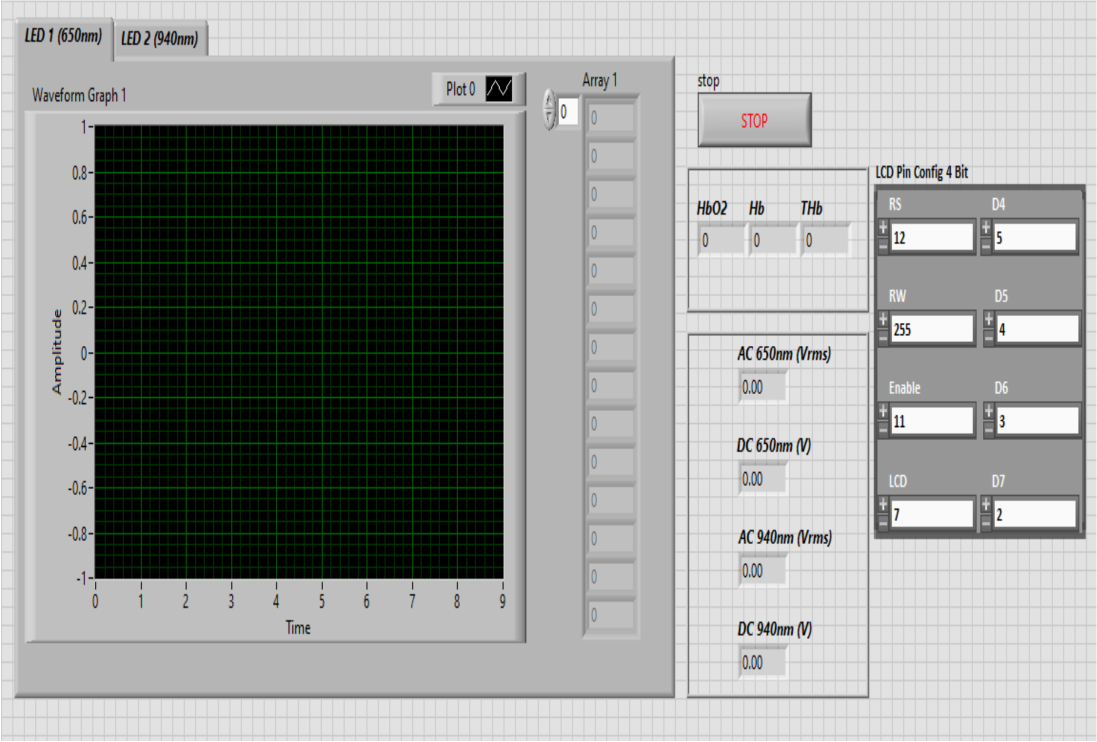
Figures (5.4) , (5.5) shows the LabVIEW code that was designed to obtain the hemoglobin concentration in the blood , in addition to the user interface, which shows the values and signal for each wavelength.

Palestine Polytechnic University
College of Engineering
Department of Electrical Engineering

Design and Implementation of a Noninvasive Anemia Detection System Using Optical Approach

Project Team
Mariam Salah
Maria Shawamreh
Manar Abo Turki

Project Supervisor:
Dr. Abdallah Arman

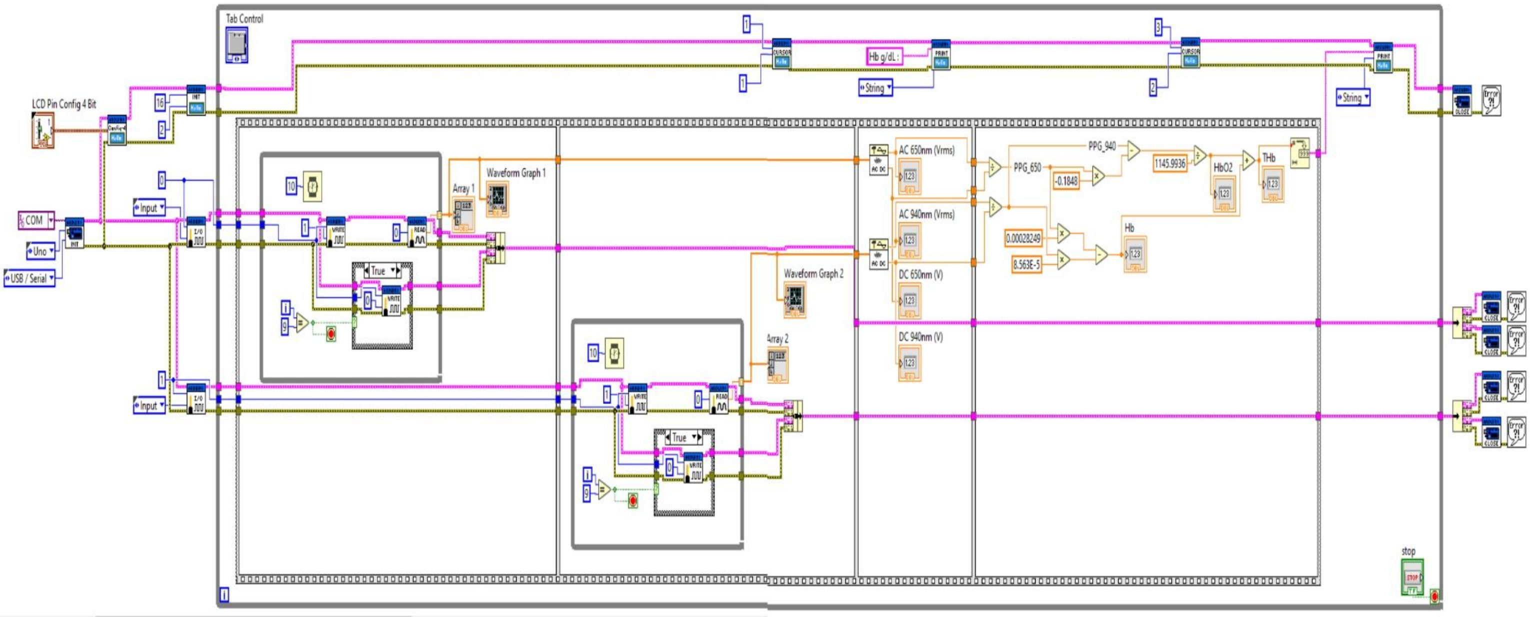


HbO2 0
Hb 0
THb 0

AC 650nm (Vrms) 0.00
DC 650nm (V) 0.00
AC 940nm (Vrms) 0.00
DC 940nm (V) 0.00

RS 12
D4 5
RW 255
D5 4
Enable 11
D6 3
LCD 7
D7 2

Figure(5.4) : User Interface.



Figure(5.5) : System LabVIEW Code .

5.3 Results of Hemoglobin Concentration

We tested the device with several people of different ages and got the results recorded in the **Table(5.1)** :

Table(5.1) : Hemoglobin Results .

Age	Hb (CBC)	Hb (By Device)
22	10.7	
22	11.3	
22	14	
27	12	
45	9.5	
75	14	
15	12	

Note :

Because of the arbitrary occupation policies, the basic parts of the project were reserved and replaced with inaccurate parts that were unable to operate the system properly.

Chapter 6 will outline some of our conclusions and some recommendations for improving the system.

6

Chapter Six

Conclusions and Recommendations

6.1 Conclusions .

6.2 Recommendations .

6.1 Conclusions

1. Anemia results from a lack of hemoglobin protein, which is the protein responsible for capturing oxygen in the lungs and delivering it to tissues to maintain life. A deficiency in this protein leads to various health problems.
2. Our project enables people to detect the presence of anemia in a safe, clean and inexpensive non-invasive way.
3. Programmed Arduino with LabVIEW software .
4. Use more leds get more accurate results .

6.2 Recommendations

Future modifications can be carried out so system performance and efficiency is improved, these modifications include:

1. Develop an application and connect it with the device to record and store data .
2. Activate an alarm related to the users status if the Hb is high or low according to age and gender .
3. Work to raise the level of accuracy for this type of equipment to compete with laboratory equipment .

Appendix A

YINDING LUXEON 3W Red light LED the property parameter.

Color	Power (W)	Voltage (V)	Current (A)	Color temperature (K/NM)	Emission Angle (°)	LUMEN (LM)
Red light	3	2.2-2.6	0.7	650-660NM	120-150	40-50
Red light	3	2.0-2.6	0.7	650-660NM	120-150	30-50

The company supports PCB board customizationservice.Please contact customer service if you need to customize PCB board.

If this product is not suitable for you, please tell us your requirements and we have other better products to offer to you.

Russia Friend Please make sure we have your FULL NAME in your address. If you do not leave us your full name, order may be lost in delivery.

Cooperation brand

Product Picture

LUXEON 3W Red light

we wholeheartedly for your service

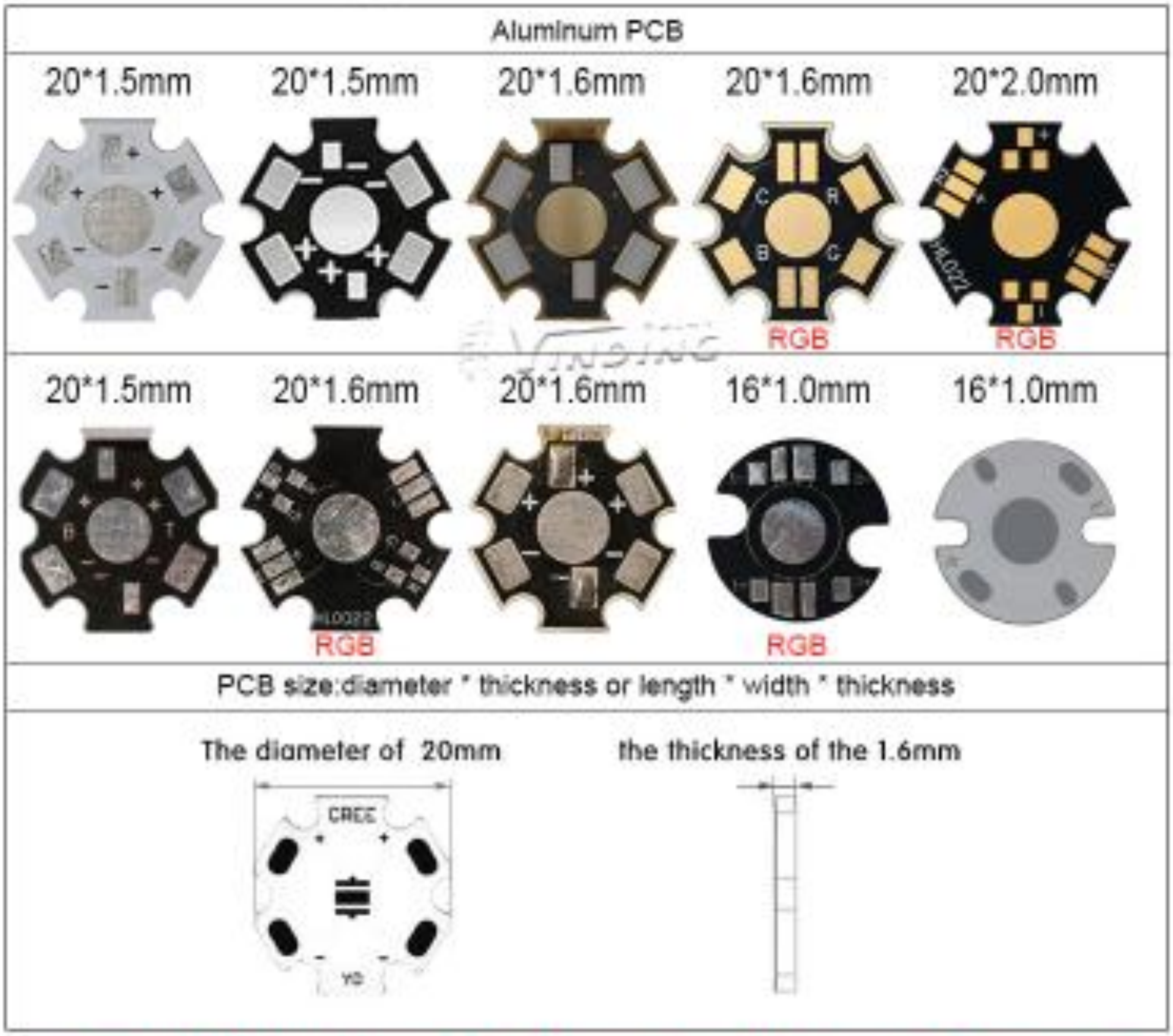
Specification and product display

LUXEON 3W Red light

YINDING LUXEON 3W Red light LED the property parameter:

Color	Power (W)	Voltage (V)	Electric Current (mA)	Color temperature (K/NM)	Emission Angle (°)	lumen (LM)
Red light	3	2.2-2.6	700	650-660NM	120-150	40-50
Red light	3	2.0-2.6	700	650-660NM	120-150	30-50

If you need it, we can help you stick the PCB board.Specific dimensions refer to the picture below to select what you want, and then complete the payment.If you don't know how to pay,you can consult customer service.



Aluminum PCB				
20*1.5mm	20*1.5mm	20*1.6mm	20*1.6mm RGB	20*2.0mm RGB
20*1.5mm	20*1.6mm RGB	20*1.6mm	16*1.0mm RGB	16*1.0mm

PCB size:diameter * thickness or length * width * thickness

The diameter of 20mm

the thickness of the 1.6mm

Note: The PCBs of the same size, the same material, the same serial connection method, and different prints have the same functions. The warehouse does not accept the specified PCB for soldering.Can solder more than 2 LED PCBs, just for display, if you need to buy, please contact customer service

If you want,please say to the customer service.
We will weld it up for you,then send it to you with electrostatic bag or blister box.

Description:the size of the measuremeent is larger than or less than 0.5mm

The light on the front.

the LED periphery adopts high light transmission PC
More than 99 per centofthe light is transmitted.
to high temperature up to 135 degrees low temperature-45 degrees

Lamp rear panel

The shell is made of aero-aluminum chrome,The main purpose is to increase the heat dissipation area and improve the heat dissipation efficiency.

Recommended reasons

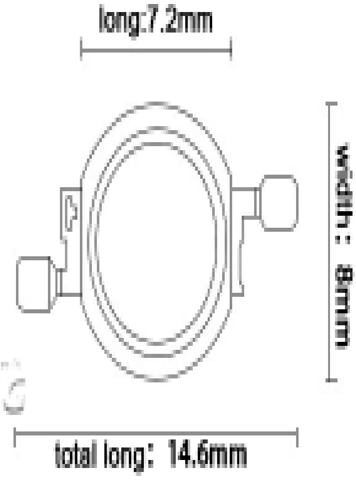
Abvantage1	Made in China YINDING LUXEON 3W Red light LED
Abvantage2	Low light failure (one hundred thousand hours minus 5%)
Abvantage3	More environmentally friendly, more power saving, quality assurance, affordable.

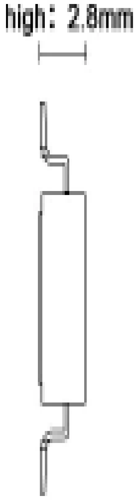
YINDING

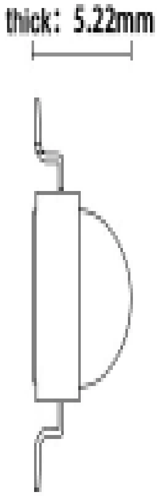
Product size

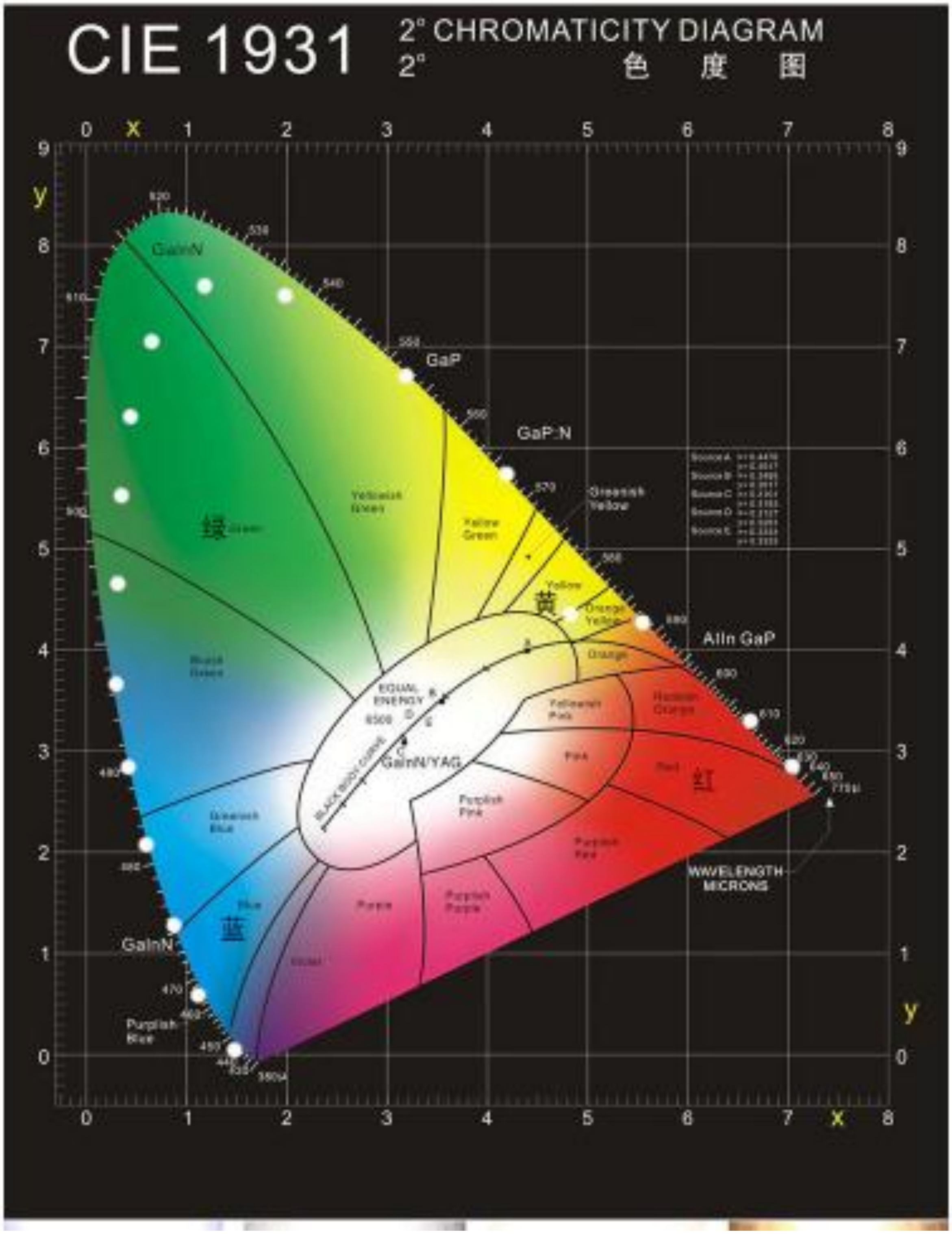
LUXEON 3W Red light

ORIGINAL RODUCT








CIE 1931
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2° 色 度 图
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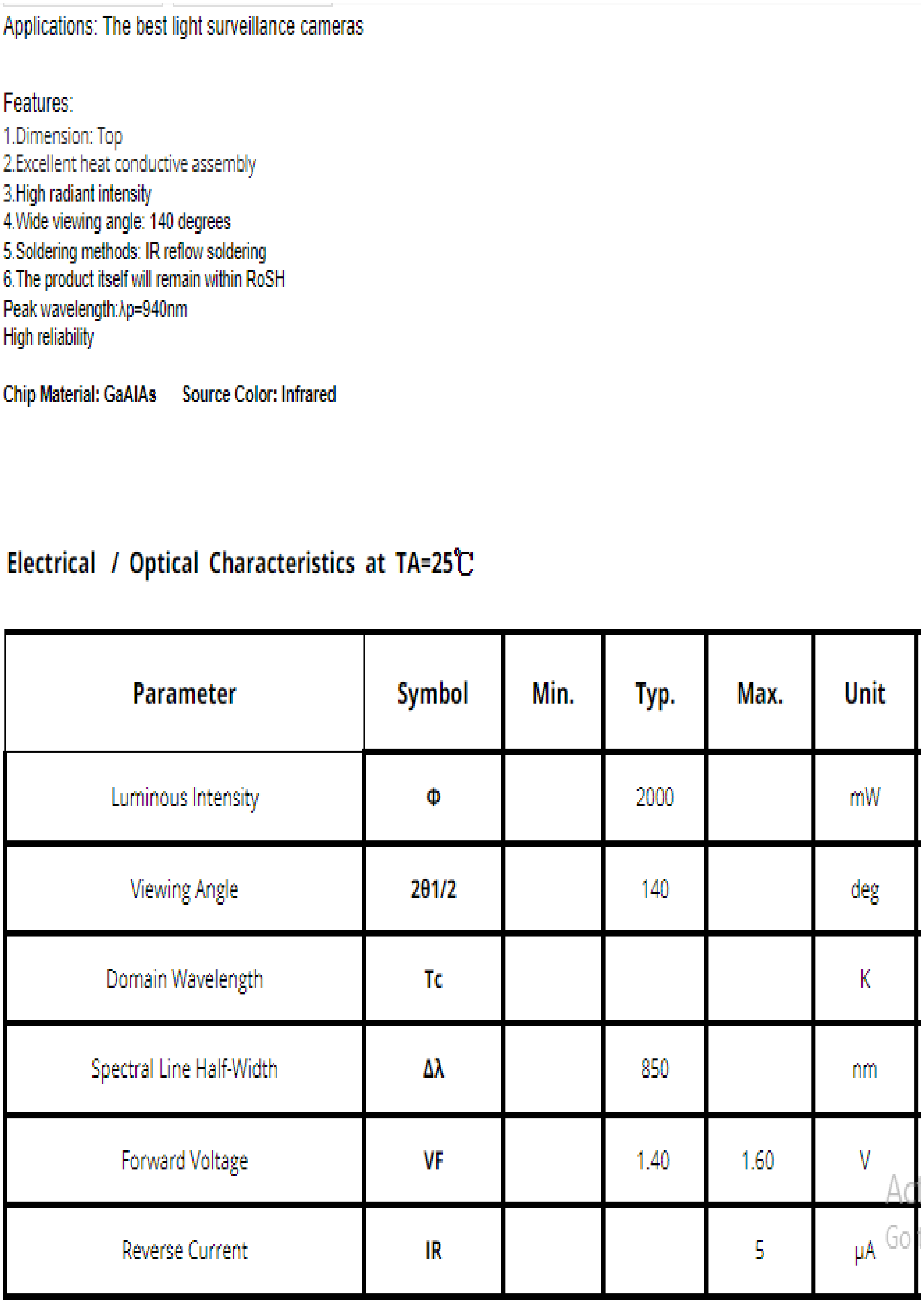
440
380
GaInN
GaP
GaP:N
AlIn GaP
GaInN/YAG
GaInN
Yellowish Green
绿 Green
Yellow Green
Greenish Yellow
Yellow
黄
Orange Yellow
Orange
Reddish Orange
Bluish Green
EQUAL ENERGY
6500
BLACK BODY CURVE
Yellowish Pink
Pink
Red
红
Greenish Blue
Purplish Pink
Purplish Red
Blue
蓝
Purple
Purplish Purple
Violet
Purplish Blue
WAVELENGTH MICRONS

Appendix B



Applications: The best light surveillance cameras

Features:

1.Dimension: Top
2.Excellent heat conductive assembly
3.High radiant intensity
4.Wide viewing angle: 140 degrees
5.Soldering methods: IR reflow soldering
6.The product itself will remain within RoSH
Peak wavelength:λp=940nm
High reliability

Chip Material: GaAIAs **Source Color: Infrared**

Electrical / Optical Characteristics at TA=25℃

Parameter	Symbol	Min.	Typ.	Max.	Unit
Luminous Intensity	**Φ**		2000		mW
Viewing Angle	**2θ1/2**		140		deg
Domain Wavelength	**Tc**				K
Spectral Line Half-Width	**Δλ**		850		nm
Forward Voltage	**VF**		1.40	1.60	V
Reverse Current	**IR**			5	μA

Absolute Maximum Ratings at TA=25℃

Parameter	Maximum Rating
Power Dissipation	1W
Peak Forward Current (1/10 Duty Cycle, 0.1ms Pulse Width)	1000mA
Reverse Voltage	5V
Operating Temperature Range	-20℃ to + 75℃
Storage Temperature Range	-30℃ to + 80℃
Lead Soldering Temperature [1.6mm(.063") From Body]	280℃ for 5 Seconds

Lifespan:
50000h
Warranty:
3 years
Chip Quantity: 1pcs 40mil
Emitted Color: Infrared IR
Viewing angle: 140 degrees.
Applied for : Security CCTV IR Camera, Remote control, Mecidal, Computer & Office

Appendix C

OPT101 Monolithic Photodiode and Single-Supply Transimpedance Amplifier

1 Features

- Single Supply: 2.7 to 36 V
- Photodiode Size: 0.090 inch × 0.090 inch (2.29 mm × 2.29 mm)
- Internal 1-MΩ Feedback Resistor
- High Responsivity: 0.45 A/W (650 nm)
- Bandwidth: 14 kHz at R_F = 1 MΩ
- Low Quiescent Current: 120 µA
- Packages: Clear Plastic 8-pin PDIP and J-Lead SOP

2 Applications

- Medical Instrumentation
- Laboratory Instrumentation
- Position and Proximity Sensors
- Photographic Analyzers
- Barcode Scanners
- Smoke Detectors
- Currency Changers

3 Description

The OPT101 is a monolithic photodiode with on-chip transimpedance amplifier. The integrated combination of photodiode and transimpedance amplifier on a single chip eliminates the problems commonly encountered in discrete designs, such as leakage current errors, noise pick-up, and gain peaking as a result of stray capacitance. Output voltage increases linearly with light intensity. The amplifier is designed for single or dual power-supply operation.

The 0.09 inch × 0.09 inch (2.29 mm × 2.29 mm) photodiode operates in the photoconductive mode for excellent linearity and low dark current.

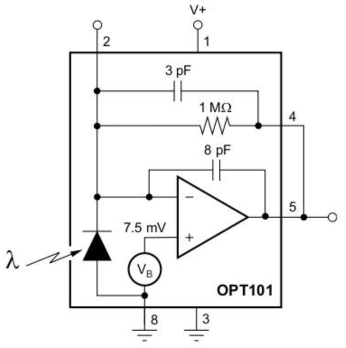
The OPT101 operates from 2.7 V to 36 V supplies and quiescent current is only 120 µA. This device is available in clear plastic 8-pin PDIP, and J-lead SOP for surface mounting. The temperature range is 0°C to 70°C.

Device Information[1]

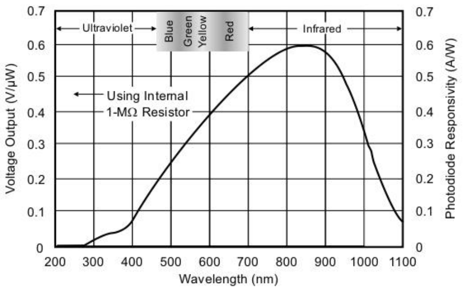
PART NUMBER	PACKAGE	BODY SIZE (NOM)
OPT101	PDIP (8)	9.53 mm × 6.52 mm
	SOP (8)	9.52 mm × 6.52 mm

(1) For all available packages, see the package option addendum at the end of the data sheet.

Block Diagram



Spectral Responsivity



6.5 Electrical Characteristics

At T_A = 25°C, V_S = 2.7 V to 36 V, λ = 650 nm, internal 1-MΩ feedback resistor, and R_L = 10 kΩ (unless otherwise noted)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
RESPONSIVITY					
Photodiode current			0.45		A/W
Voltage output			0.45		V/μW
Voltage output vs temperature			100		ppm/°C
Unit-to-unit variation			±5%		
Nonlinearity (1)	Full-scale (FS) output = 24 V		±0.01		% of FS
Photodiode area	0.090 in × 0.090 in		0.008		in^2
	2.29 mm × 2.29 mm		5.2		mm^2
DARK ERRORS, RTO (2)					
Offset voltage, output		5	7.5	10	mV
Offset voltage vs temperature			±10		μV/°C
Offset voltage vs power supply	V_S = 2.7 V to 36 V		10	100	μV/V
Voltage noise, dark	f_B = 0.1 Hz to 20 kHz, V_S = 15 V, V_{PIN3} = –15 V		300		μVrms
TRANSIMPEDANCE GAIN					
Resistor			1		MΩ
Tolerance			±0.5%	±2%	
Tolerance vs temperature			±50		ppm/°C
FREQUENCY RESPONSE					
Bandwidth	V_{OUT} = 10 V_{PP}		14		kHz
Rise and fall time	10% to 90%, V_{OUT} = 10-V step		28		μs
Settling time	to 0.05%, V_{OUT} = 10-V step		160		μs
	to 0.1%, V_{OUT} = 10-V step		80		μs
	to 1%, V_{OUT} = 10-V step		70		μs
Overload recovery	100%, return to linear operation		50		μs
OUTPUT					
Voltage output, high		(V_S) – 1.3	(V_S) – 1.15		V
Capacitive load, stable operation			10		nF
Short-circuit current	V_S = 36 V		15		mA
POWER SUPPLY					
Quiescent current	Dark, V_{PIN3} = 0 V		120		μA
	R_L = ∞, V_{OUT} = 10 V		220		μA

(1) Deviation in percent of full scale from best-fit straight line.
(2) Referred to output. Includes all error sources.

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted) (1)

		MIN	MAX	UNIT
Supply voltage (V_S to Common pin or –V pin)		0	36	V
Output short-circuit (to ground)		Continuous		
Temperature	Operating	–25	85	°C
	Junction		85	°C
	Storage, T_{stg}	–25	85	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 (1)	±2000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101 (2)	±500	

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

	MIN	NOM	MAX	UNIT
POWER SUPPLY				
Operating voltage	2.7		36	V
TEMPERATURE				
Specified	0		70	°C
Operating	0		70	°C

6.4 Thermal Information

	THERMAL METRIC (1)	OPT101		UNIT
		DTL (SOP)	NTC (PDIP)	
		8 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	138.6	128.2	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	96.4	113.1	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	126.6	107.0	°C/W
ψ_{JT}	Junction-to-top characterization parameter	17.8	24.2	°C/W
ψ_{JB}	Junction-to-board characterization parameter	118.8	105.9	°C/W

(1) For more information about traditional and new thermal metrics, see the *Semiconductor and IC Package Thermal Metrics* application report, SPRA953.

6.8 Typical Characteristics

At T_A = 25°C, V_S = 2.7 V to 36 V, λ = 650 nm, internal 1-MΩ feedback resistor, and R_L = 10 kΩ (unless otherwise noted)

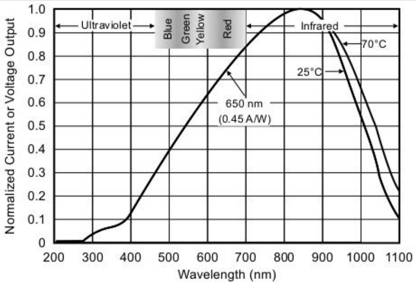


Figure 1. Normalized Spectral Responsivity

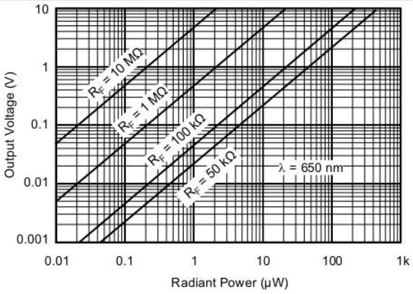


Figure 2. Voltage Responsivity vs Radiant Power

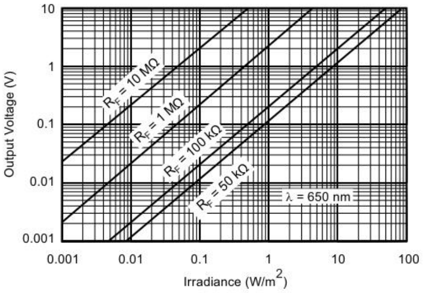


Figure 3. Voltage Responsivity vs Irradiance

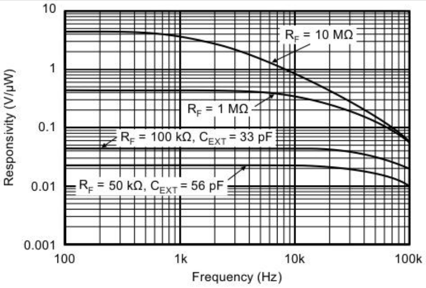


Figure 4. Voltage Responsivity vs Frequency

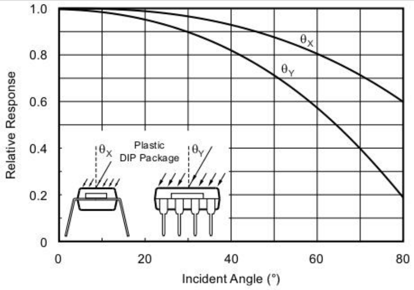


Figure 5. Response vs Incident Angle

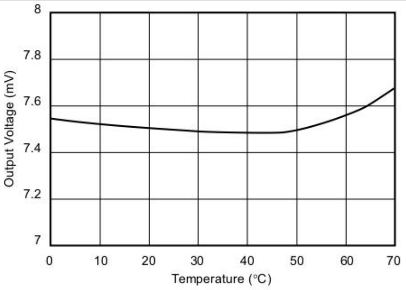


Figure 6. Dark V_{OUT} vs Temperature

Appendix D

ANALOG DEVICES

Single-Supply, Rail-to-Rail Low Power FET-Input Op Amp

Data Sheet

AD822

FEATURES

- **True single-supply operation**
  - **Output swings rail-to-rail**
  - **Input voltage range extends below ground**
  - **Single-supply capability from 5 V to 30 V**
  - **Dual-supply capability from ±2.5 V to ±15 V**
- **High load drive**
  - **Capacitive load drive of 350 pF, G = +1**
  - **Minimum output current of 15 mA**
- **Excellent ac performance for low power**
  - **800 μA maximum quiescent current per amplifier**
  - **Unity-gain bandwidth: 1.8 MHz**
  - **Slew rate of 3 V/μs**
- **Good dc performance**
  - **800 μV maximum input offset voltage**
  - **2 μV/°C typical offset voltage drift**
  - **25 pA maximum input bias current**
- **Low noise**
  - **13 nV/√Hz at 10 kHz**
  - **No phase inversion**

APPLICATIONS

- **Battery-powered precision instrumentation**
- **Photodiode preamps**
- **Active filters**
- **12-bit to 14-bit data acquisition systems**
- **Medical instrumentation**
- **Low power references and regulators**

GENERAL DESCRIPTION

The AD822 is a dual precision, low power FET input op amp that can operate from a single supply of 5 V to 30 V or from dual supplies of ±2.5 V to ±15 V. It has true single-supply capability with an input voltage range extending below the negative rail, allowing the AD822 to accommodate input signals below ground while in the single-supply mode. Output voltage swing extends to within 10 mV of each rail, providing the maximum output dynamic range.

Offset voltage of 800 μV maximum, offset voltage drift of 2 μV/°C, input bias currents below 25 pA, and low input voltage noise provide dc precision with source impedances up to a gigaohm. The 1.8 MHz unity-gain bandwidth, −93 dB total harmonic distortion (THD) at 10 kHz, and 3 V/μs slew rate are provided with a low supply current of 800 μA per amplifier.

CONNECTION DIAGRAM

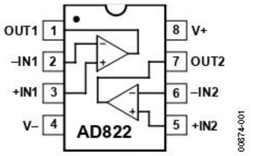


Figure 1. 8-Lead PDIP (N Suffix); 8-Lead MSOP (RM Suffix); and 8-Lead SOIC_N (R Suffix)

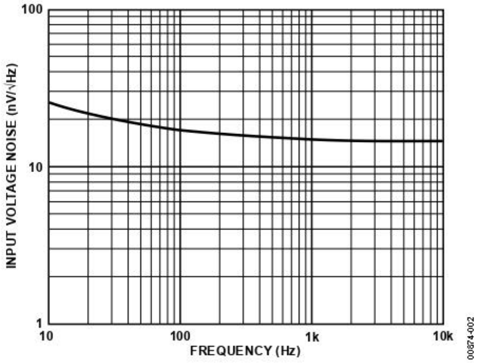


Figure 2. Input Voltage Noise vs. Frequency

Rev. J
Document Feedback

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Technical Support
www.analog.com

SPECIFICATIONS

V_S = 0 V, 5 V at T_A = 25°C, V_{CM} = 0 V, V_{OUT} = 0.2 V, unless otherwise noted.

Table 1.

			A Grade			B Grade		
Parameter	**Test Conditions/Comments**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Unit**
DC PERFORMANCE								
Initial Offset			0.1	0.8		0.1	0.4	mV
Maximum Offset Over Temperature			0.5	1.2		0.5	0.9	mV
Offset Drift			2			2		μV/°C
Input Bias Current	V_{CM} = 0 V to 4 V		2	25		2	10	pA
At T_{MAX}			0.5	5		0.5	2.5	nA
Input Offset Current			2	20		2	10	pA
At T_{MAX}			0.5			0.5		nA
Open-Loop Gain	V_{OUT} = 0.2 V to 4 V							
	R_L = 100 kΩ	500	1000		500	1000		V/mV
T_{MIN} to T_{MAX}		400			400			V/mV
	R_L = 10 kΩ	80	150		80	150		V/mV
T_{MIN} to T_{MAX}		80			80			V/mV
	R_L = 1 kΩ	15	30		15	30		V/mV
T_{MIN} to T_{MAX}		10			10			V/mV
NOISE/HARMONIC PERFORMANCE								
Input Voltage Noise								
f = 0.1 Hz to 10 Hz			2			2		μV p-p
f = 10 Hz			25			25		nV/√Hz
f = 100 Hz			21			21		nV/√Hz
f = 1 kHz			16			16		nV/√Hz
f = 10 kHz			13			13		nV/√Hz
Input Current Noise								
f = 0.1 Hz to 10 Hz			18			18		fA p-p
f = 1 kHz			0.8			0.8		fA/√Hz
Harmonic Distortion	R_L = 10 kΩ to 2.5 V							
f = 10 kHz	V_{OUT} = 0.25 V to 4.75 V		−93			−93		dB
DYNAMIC PERFORMANCE								
Unity-Gain Frequency			1.8			1.8		MHz
Full Power Response	V_{OUT} p-p = 4.5 V		210			210		kHz
Slew Rate			3			3		V/μs
Settling Time								
To 0.1%	V_{OUT} = 0.2 V to 4.5 V		1.4			1.4		μs
To 0.01%	V_{OUT} = 0.2 V to 4.5 V		1.8			1.8		μs
MATCHING CHARACTERISTICS								
Initial Offset				1.0			0.5	mV
Maximum Offset Over Temperature				1.6			1.3	mV
Offset Drift			3			3		μV/°C
Input Bias Current				20			10	pA
Crosstalk @ f = 1 kHz	R_L = 5 kΩ		−130			−130		dB
Crosstalk @ f = 100 kHz	R_L = 5 kΩ		−93			−93		dB

Parameter	Test Conditions/Comments	A Grade			B Grade			Unit
		Min	Typ	Max	Min	Typ	Max	
INPUT CHARACTERISTICS								
Input Voltage Range[1], T_{MIN} to T_{MAX}		−0.2		+4	−0.2		+4	V
Common-Mode Rejection Ratio (CMRR)	$V_{CM} = 0$ V to 2 V	66	80		69	80		dB
T_{MIN} to T_{MAX}	$V_{CM} = 0$ V to 2 V	66			66			dB
Input Impedance								
Differential			10^{13}‖0.5			10^{13}‖0.5		Ω‖pF
Common Mode			10^{13}‖2.8			10^{13}‖2.8		Ω‖pF
OUTPUT CHARACTERISTICS								
Output Saturation Voltage[2]								
$V_{OL} - V_{EE}$	$I_{SINK} = 20$ µA		5	7		5	7	mV
T_{MIN} to T_{MAX}				10			10	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 20$ µA		10	14		10	14	mV
T_{MIN} to T_{MAX}				20			20	mV
$V_{OL} - V_{EE}$	$I_{SINK} = 2$ mA		40	55		40	55	mV
T_{MIN} to T_{MAX}				80			80	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 2$ mA		80	110		80	110	mV
T_{MIN} to T_{MAX}				160			160	mV
$V_{OL} - V_{EE}$	$I_{SINK} = 15$ mA		300	500		300	500	mV
T_{MIN} to T_{MAX}				1000			1000	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 15$ mA		800	1500		800	1500	mV
T_{MIN} to T_{MAX}				1900			1900	mV
Operating Output Current		15			15			mA
T_{MIN} to T_{MAX}		12			12			mA
Capacitive Load Drive			350			350		pF
POWER SUPPLY								
Quiescent Current, T_{MIN} to T_{MAX}			1.24	1.6		1.24	1.6	mA
Power Supply Rejection	V+ = 5 V to 15 V	66	80		70	80		dB
T_{MIN} to T_{MAX}		66			70			dB

[1] This is a functional specification. Amplifier bandwidth decreases when the input common-mode voltage is driven in the range (V+ − 1 V) to V+. Common-mode error voltage is typically less than 5 mV with the common-mode voltage set at 1 V below the positive supply.

[2] $V_{OL} - V_{EE}$ is defined as the difference between the lowest possible output voltage (V_{OL}) and the negative voltage supply rail (V_{EE}). $V_{CC} - V_{OH}$ is defined as the difference between the highest possible output voltage (V_{OH}) and the positive supply voltage (V_{CC}).

$V_S = \pm 5$ V at $T_A = 25°C$, $V_{CM} = 0$ V, $V_{OUT} = 0$ V, unless otherwise noted.

Table 2.

Parameter	Test Conditions/Comments	A Grade			B Grade			Unit
		Min	Typ	Max	Min	Typ	Max	
DC PERFORMANCE								
Initial Offset			0.1	0.8		0.1	0.4	mV
Maximum Offset Over Temperature			0.5	1.5		0.5	1	mV
Offset Drift			2			2		μV/°C
Input Bias Current	$V_{CM} = -5$ V to +4 V		2	25		2	10	pA
At T_{MAX}			0.5	5		0.5	2.5	nA
Input Offset Current			2	20		2	10	pA
At T_{MAX}			0.5			0.5		nA
Open-Loop Gain	$V_{OUT} = -4$ V to +4 V							
	$R_L = 100$ kΩ	400	1000		400	1000		V/mV
T_{MIN} to T_{MAX}		400			400			V/mV
	$R_L = 10$ kΩ	80	150		80	150		V/mV
T_{MIN} to T_{MAX}		80			80			V/mV
	$R_L = 1$ kΩ	20	30		20	30		V/mV
T_{MIN} to T_{MAX}		10			10			V/mV
NOISE/HARMONIC PERFORMANCE								
Input Voltage Noise								
f = 0.1 Hz to 10 Hz			2			2		μV p-p
f = 10 Hz			25			25		nV/√Hz
f = 100 Hz			21			21		nV/√Hz
f = 1 kHz			16			16		nV/√Hz
f = 10 kHz			13			13		nV/√Hz
Input Current Noise								
f = 0.1 Hz to 10 Hz			18			18		fA p-p
f = 1 kHz			0.8			0.8		fA/√Hz
Harmonic Distortion	$R_L = 10$ kΩ							
f = 10 kHz	$V_{OUT} = \pm 4.5$ V		−93			−93		dB
DYNAMIC PERFORMANCE								
Unity-Gain Frequency			1.9			1.9		MHz
Full Power Response	V_{OUT} p-p = 9 V		105			105		kHz
Slew Rate			3			3		V/μs
Settling Time								
to 0.1%	$V_{OUT} = 0$ V to ±4.5 V		1.4			1.4		μs
to 0.01%	$V_{OUT} = 0$ V to ±4.5 V		1.8			1.8		μs
MATCHING CHARACTERISTICS								
Initial Offset				1.0			0.5	mV
Maximum Offset Over Temperature				3			2	mV
Offset Drift			3			3		μV/°C
Input Bias Current				25			10	pA
Crosstalk @ f = 1 kHz	$R_L = 5$ kΩ		−130			−130		dB
Crosstalk @ f = 100 kHz	$R_L = 5$ kΩ		−93			−93		dB
INPUT CHARACTERISTICS								
Input Voltage Range[1], T_{MIN} to T_{MAX}		−5.2		+4	−5.2		+4	V
Common-Mode Rejection Ratio (CMRR)	$V_{CM} = -5$ V to +2 V	66	80		69	80		dB
T_{MIN} to T_{MAX}	$V_{CM} = -5$ V to +2 V	66			66			dB
Input Impedance								
Differential			$10^{13}\parallel 0.5$			$10^{13}\parallel 0.5$		Ω∥pF
Common Mode			$10^{13}\parallel 2.8$			$10^{13}\parallel 2.8$		Ω∥pF

			A Grade			B Grade		
Parameter	**Test Conditions/Comments**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Unit**
OUTPUT CHARACTERISTICS								
Output Saturation Voltage[2]								
$V_{OL} - V_{EE}$	I_{SINK} = 20 µA		5	7		5	7	mV
T_{MIN} to T_{MAX}				10			10	mV
$V_{CC} - V_{OH}$	I_{SOURCE} = 20 µA		10	14		10	14	mV
T_{MIN} to T_{MAX}				20			20	mV
$V_{OL} - V_{EE}$	I_{SINK} = 2 mA		40	55		40	55	mV
T_{MIN} to T_{MAX}				80			80	mV
$V_{CC} - V_{OH}$	I_{SOURCE} = 2 mA		80	110		80	110	mV
T_{MIN} to T_{MAX}				160			160	mV
$V_{OL} - V_{EE}$	I_{SINK} = 15 mA		300	500		300	500	mV
T_{MIN} to T_{MAX}				1000			1000	mV
$V_{CC} - V_{OH}$	I_{SOURCE} = 15 mA		800	1500		800	1500	mV
T_{MIN} to T_{MAX}				1900			1900	mV
Operating Output Current		15			15			mA
T_{MIN} to T_{MAX}		12			12			mA
Capacitive Load Drive			350			350		pF
POWER SUPPLY								
Quiescent Current, T_{MIN} to T_{MAX}			1.3	1.6		1.3	1.6	mA
Power Supply Rejection	V_{SY} = ±5 V to ±15 V	66	80		70	80		dB
T_{MIN} to T_{MAX}		66			70			dB

[1] This is a functional specification. Amplifier bandwidth decreases when the input common-mode voltage is driven in the range (V+ − 1 V) to V+. Common-mode error voltage is typically less than 5 mV with the common-mode voltage set at 1 V below the positive supply.

[2] $V_{OL} - V_{EE}$ is defined as the difference between the lowest possible output voltage (V_{OL}) and the negative voltage supply rail (V_{EE}). $V_{CC} - V_{OH}$ is defined as the difference between the highest possible output voltage (V_{OH}) and the positive supply voltage (V_{CC}).

V_S = ±15 V at T_A = 25°C, V_{CM} = 0 V, V_{OUT} = 0 V, unless otherwise noted.

Table 3.

		A Grade			B Grade			
Parameter	**Test Conditions/Comments**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Unit**
DC PERFORMANCE								
Initial Offset			0.4	2		0.3	1.5	mV
Maximum Offset Over Temperature			0.5	3		0.5	2.5	mV
Offset Drift			2			2		μV/°C
Input Bias Current	V_{CM} = 0 V		2	25		2	12	pA
	V_{CM} = −10 V		40			40		pA
At T_{MAX}	V_{CM} = 0 V		0.5	5		0.5	2.5	nA
Input Offset Current			2	20		2	12	pA
At T_{MAX}			0.5			0.5		nA
Open-Loop Gain	V_{OUT} = −10 V to +10 V							
	R_L = 100 kΩ	500	2000		500	2000		V/mV
T_{MIN} to T_{MAX}		500			500			V/mV
	R_L = 10 kΩ	100	500		100	500		V/mV
T_{MIN} to T_{MAX}		100			100			V/mV
	R_L = 1 kΩ	30	45		30	45		V/mV
T_{MIN} to T_{MAX}		20			20			V/mV
NOISE/HARMONIC PERFORMANCE								
Input Voltage Noise								
f = 0.1 Hz to 10 Hz			2			2		μV p-p
f = 10 Hz			25			25		nV/√Hz
f = 100 Hz			21			21		nV/√Hz
f = 1 kHz			16			16		nV/√Hz
f = 10 kHz			13			13		nV/√Hz
Input Current Noise								
f = 0.1 Hz to 10 Hz			18			18		fA p-p
f = 1 kHz			0.8			0.8		fA/√Hz
Harmonic Distortion	R_L = 10 kΩ							
f = 10 kHz	V_{OUT} = ±10 V		−85			−85		dB
DYNAMIC PERFORMANCE								
Unity-Gain Frequency			1.9			1.9		MHz
Full Power Response	V_{OUT} p-p = 20 V		45			45		kHz
Slew Rate			3			3		V/μs
Settling Time								
to 0.1%	V_{OUT} = 0 V to ±10 V		4.1			4.1		μs
to 0.01%	V_{OUT} = 0 V to ±10 V		4.5			4.5		μs
MATCHING CHARACTERISTICS								
Initial Offset				3			2	mV
Maximum Offset Over Temperature				4			2.5	mV
Offset Drift			3			3		μV/°C
Input Bias Current				25			12	pA
Crosstalk @ f = 1 kHz	R_L = 5 kΩ		−130			−130		dB
Crosstalk @ f = 100 kHz	R_L = 5 kΩ		−93			−93		dB
INPUT CHARACTERISTICS								
Input Voltage Range[1], T_{MIN} to T_{MAX}		−15.2		+14	−15.2		+14	V
Common-Mode Rejection Ratio (CMRR)	V_{CM} = −15 V to +12 V	70	80		74	90		dB
T_{MIN} to T_{MAX}	V_{CM} = −15 V to +12 V	70			74			dB
Input Impedance								
Differential			$10^{13}\|\|0.5$			$10^{13}\|\|0.5$		Ω||pF
Common Mode			$10^{13}\|\|2.8$			$10^{13}\|\|2.8$		Ω||pF

Parameter	Test Conditions/Comments	A Grade Min	A Grade Typ	A Grade Max	B Grade Min	B Grade Typ	B Grade Max	Unit
OUTPUT CHARACTERISTICS								
Output Saturation Voltage[2]								
$V_{OL} - V_{EE}$	$I_{SINK} = 20\ \mu A$		5	7		5	7	mV
T_{MIN} to T_{MAX}				10			10	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 20\ \mu A$		10	14		10	14	mV
T_{MIN} to T_{MAX}				20			20	mV
$V_{OL} - V_{EE}$	$I_{SINK} = 2$ mA		40	55		40	55	mV
T_{MIN} to T_{MAX}				80			80	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 2$ mA		80	110		80	110	mV
T_{MIN} to T_{MAX}				160			160	mV
$V_{OL} - V_{EE}$	$I_{SINK} = 15$ mA		300	500		300	500	mV
T_{MIN} to T_{MAX}				1000			1000	mV
$V_{CC} - V_{OH}$	$I_{SOURCE} = 15$ mA		800	1500		800	1500	mV
T_{MIN} to T_{MAX}				1900			1900	mV
Operating Output Current		20			20			mA
T_{MIN} to T_{MAX}		15			15			mA
Capacitive Load Drive			350			350		pF
POWER SUPPLY								
Quiescent Current, T_{MIN} to T_{MAX}			1.4	1.8		1.4	1.8	mA
Power Supply Rejection	$V_{SY} = \pm 5$ V to ± 15 V	70	80		70	80		dB
T_{MIN} to T_{MAX}		70			70			dB

[1] This is a functional specification. Amplifier bandwidth decreases when the input common-mode voltage is driven in the range (V+ − 1 V) to V+. Common-mode error voltage is typically less than 5 mV with the common-mode voltage set at 1 V below the positive supply.

[2] $V_{OL} - V_{EE}$ is defined as the difference between the lowest possible output voltage (V_{OL}) and the negative voltage supply rail (V_{EE}). $V_{CC} - V_{OH}$ is defined as the difference between the highest possible output voltage (V_{OH}) and the positive supply voltage (V_{CC}).

Appendix E

September 2014

LM78XX / LM78XXA
3-Terminal 1 A Positive Voltage Regulator

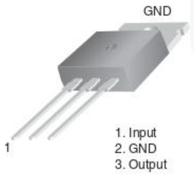
Features

- Output Current up to 1 A
- Output Voltages: 5, 6, 8, 9, 10, 12, 15, 18, 24 V
- Thermal Overload Protection
- Short-Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The LM78XX series of three-terminal positive regulators is available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut-down, and safe operating area protection. If adequate heat sinking is provided, they can deliver over 1 A output current. Although designed primarily as fixed-voltage regulators, these devices can be used with external components for adjustable voltages and currents.

TO-220 (Single Gauge)



Ordering Information(1)

Product Number	Output Voltage Tolerance	Package	Operating Temperature	Packing Method
LM7805CT	±4%	TO-220 (Single Gauge)	-40°C to +125°C	Rail
LM7806CT				
LM7808CT				
LM7809CT				
LM7810CT				
LM7812CT				
LM7815CT				
LM7818CT				
LM7824CT				
LM7805ACT	±2%		0°C to +125°C	
LM7809ACT				
LM7810ACT				
LM7812ACT				
LM7815ACT				

Note:

1. Above output voltage tolerance is available at 25°C.

Electrical Characteristics (LM7805)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 10 V, C_I = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		4.80	5.00	5.20	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 7 V to 20 V		4.75	5.00	5.25	
Regline	Line Regulation$^{(2)}$	T_J = +25°C	V_I = 7 V to 25 V		4.0	100.0	mV
			V_I = 8 V to 12 V		1.6	50.0	
Regload	Load Regulation$^{(2)}$	T_J = +25°C	I_O = 5 mA to 1.5 A		9.0	100.0	mV
			I_O = 250 mA to 750 mA		4.0	50.0	
I_Q	Quiescent Current	T_J = +25°C			5	8	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A			0.03	0.50	mA
		V_I = 7 V to 25 V			0.30	1.30	
$\Delta V_O/\Delta T$	Output Voltage Drift$^{(3)}$	I_O = 5 mA			-0.8		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			42		µV
RR	Ripple Rejection$^{(3)}$	f = 120 Hz, V_I = 8 V to 18 V		62	73		dB
V_{DROP}	Dropout Voltage	T_J = +25°C, I_O = 1 A			2		V
R_O	Output Resistance$^{(3)}$	f = 1 kHz			15		mΩ
I_{SC}	Short-Circuit Current	T_J = +25°C, V_I = 35 V			230		mA
I_{PK}	Peak Current$^{(3)}$	T_J = +25°C			2.2		A

Notes:

2. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
3. These parameters, although guaranteed, are not 100% tested in production.

Typical Performance Characteristics

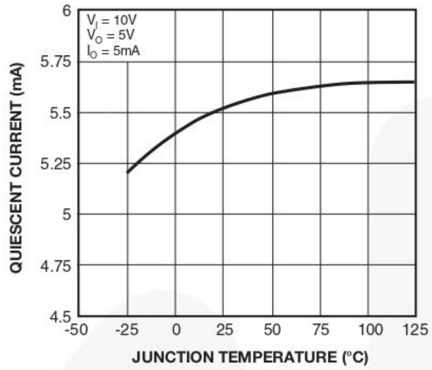


Figure 2. Quiescent Current

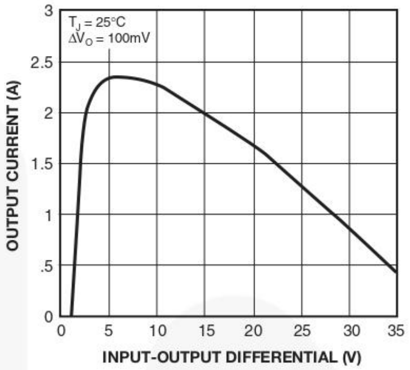


Figure 3. Peak Output Current

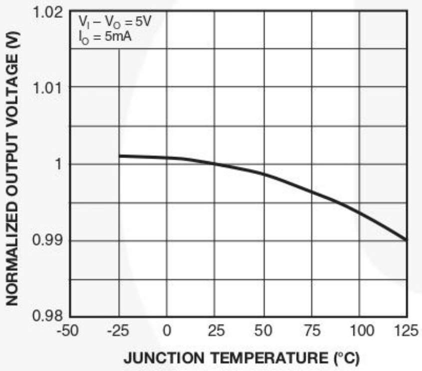


Figure 4. Output Voltage

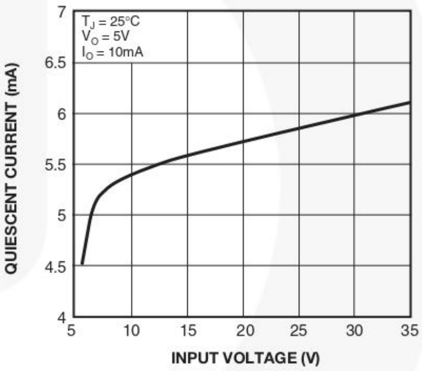


Figure 5. Quiescent Current

Typical Applications

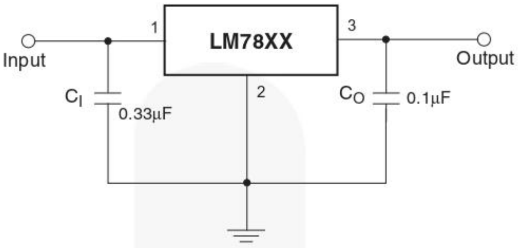


Figure 6. DC Parameters

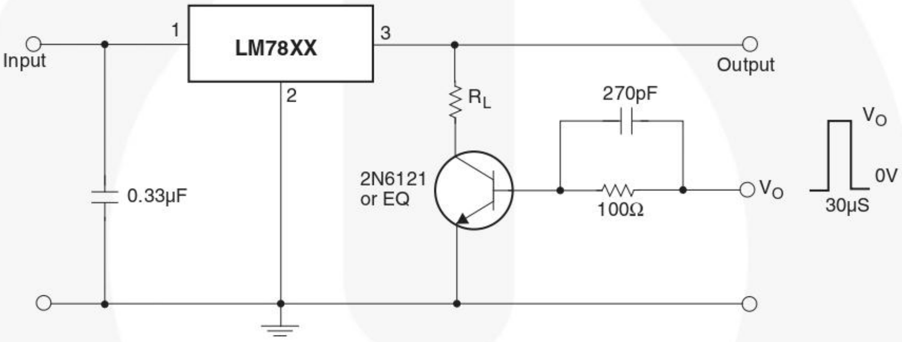


Figure 7. Load Regulation

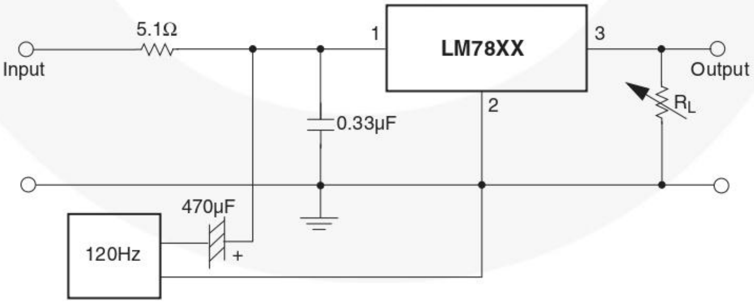


Figure 8. Ripple Rejection

Typical Applications (Continued)

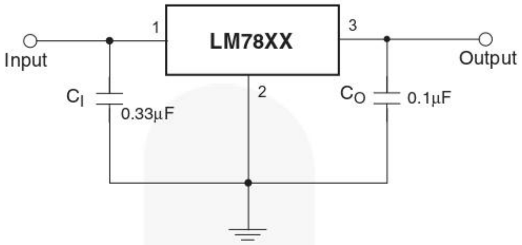
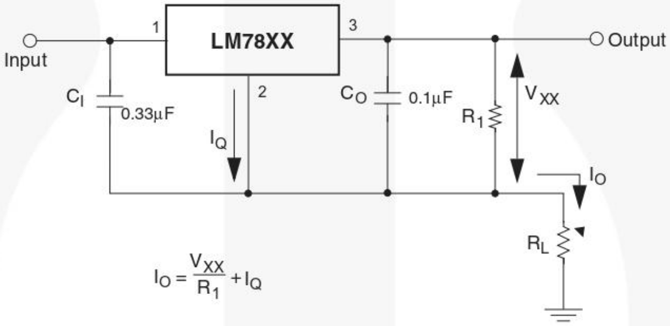


Figure 9. Fixed-Output Regulator



$$I_O = \frac{V_{XX}}{R_1} + I_Q$$

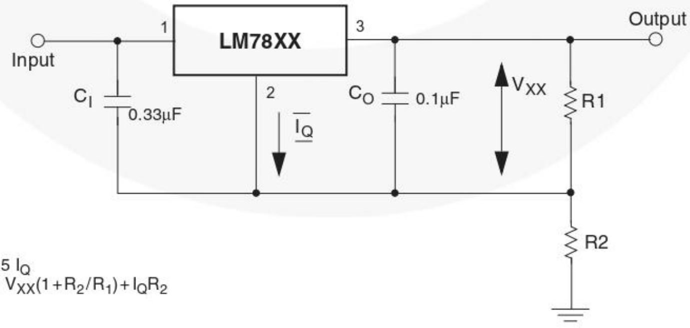
Figure 10. Constant Current Regulator

Notes:

29. To specify an output voltage, substitute voltage value for "XX". A common ground is required between the input and the output voltage. The input voltage must remain typically 2.0 V above the output voltage even during the low point on the input ripple voltage.

30. C_I is required if regulator is located an appreciable distance from power supply filter.

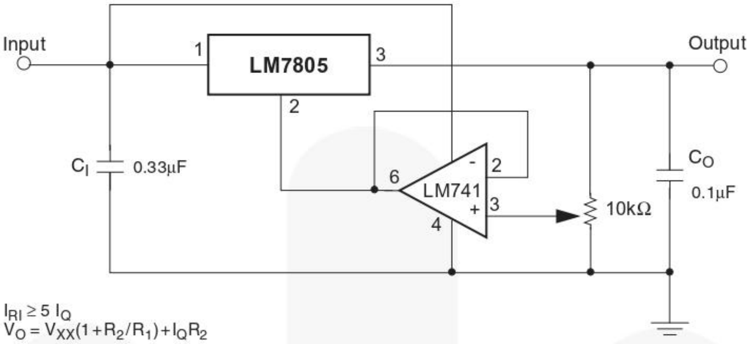
31. C_O improves stability and transient response.



$I_{RI} \geq 5\ I_Q$
$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$

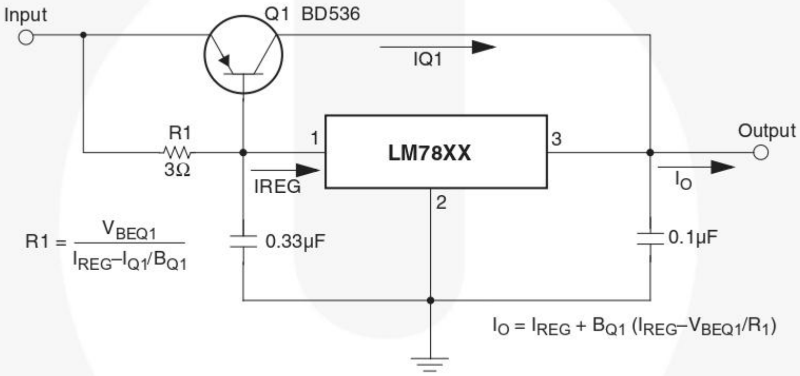
Figure 11. Circuit for Increasing Output Voltage

Typical Applications (Continued)



$I_{RI} \geq 5\ I_Q$
$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$

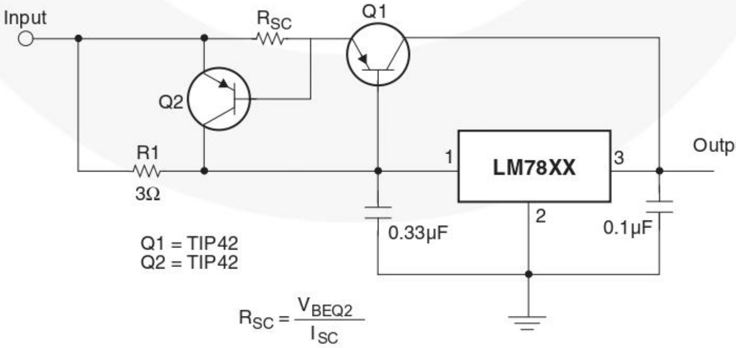
Figure 12. Adjustable Output Regulator (7 V to 30 V)



$R1 = \frac{V_{BEQ1}}{I_{REG}-I_{Q1}/B_{Q1}}$

$I_O = I_{REG} + B_{Q1}\ (I_{REG}-V_{BEQ1}/R_1)$

Figure 13. High-Current Voltage Regulator



Q1 = TIP42
Q2 = TIP42

$R_{SC} = \frac{V_{BEQ2}}{I_{SC}}$

Figure 14. High Output Current with Short-Circuit Protection

Typical Applications (Continued)

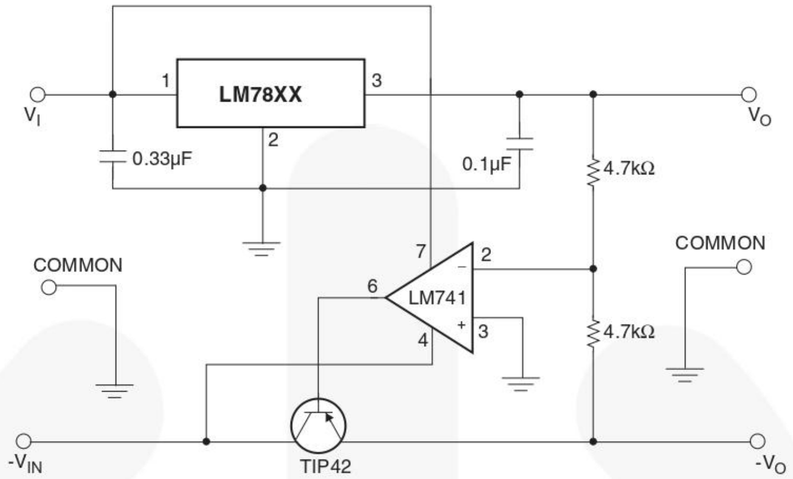


Figure 15. Tracking Voltage Regulator

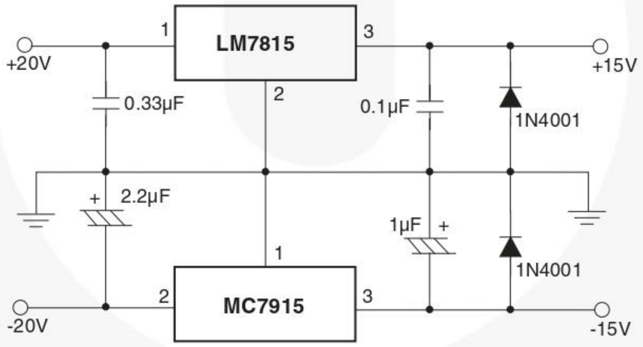


Figure 16. Split Power Supply (±15 V - 1 A)

Typical Applications (Continued)

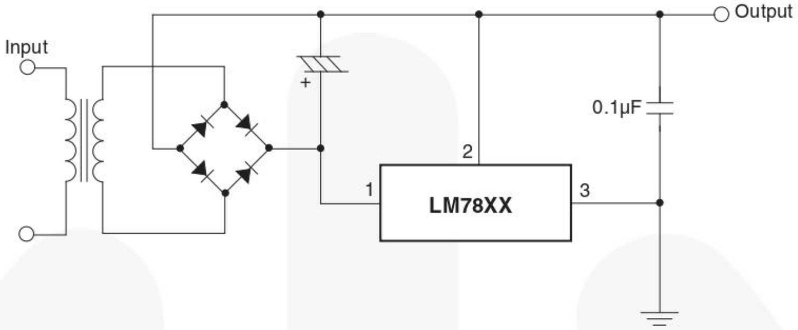


Figure 17. Negative Output Voltage Circuit

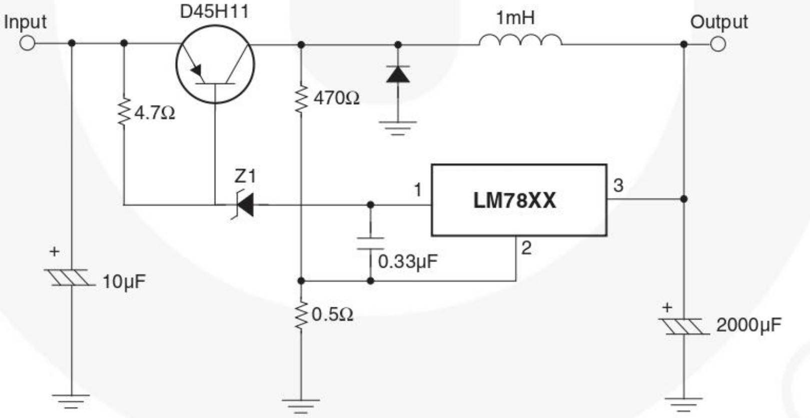


Figure 18. Switching Regulator

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