Palestine Polytechnic University
College of Engineering
Electrical Engineering Department
Biomedical Engineering

Graduation Project

Design of an Optical Non-Invasive Device for Measuring Bilirubin and a Home Use Phototherapy

Project Team

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Supervisor

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By the guidance of our supervisor , and the acceptance of all members in the testing committee , this project is delivered to the electrical engineering department in the college of engineering , to be as a partial fulfillment of Bachelor of engineering degree requirements .

Supervisor Signature

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Testing Committee Signatures

______________________ ______________________ ______________________

Department Head Signature

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جامعة بوليتكنك فلسطين

كلية الهندسة

دائرة الهندسة الكهربائية

هندسة الاجهزة الطبية

Design of an Optical Non-Invasive Device for Measuring Bilirubin and a Home Use Phototherapy

فريق المشروع

آدم جميل العبد   معاذ سليمان وهدان

بناء على نظام كلية الهندسة ، و اشراف و متابعة المشرف المباشر على المشروع ، و موافقة اعضاء اللجنة المناقشة ، تم تقديم هذا العمل الى دائرة الهندسة الكهربائية ، و ذلك للوفاء بمتطلبات درجة البكالوريوس في هندسة الاجهزة الطبية .

توقيع المشرف

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توقيع اللجنة المناقشة

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توقيع رئيس الدائرة

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Acknowledgment

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With all the gratitude , thanks for everyone who stood up with us , and reached to us with their hands to make us stand up again .

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To our families , parents , friends , and the ones we love , none of what we did was going to be possible without you , you were the strength for us .

At last but not least , thanks to all of our teachers and instructors , you’ve directed us to the start of the road , hope we will make each of you proud of us .

Abstract

Bilirubin is a yellow substance created when the red blood cells are broke down , then bilirubin breaks down in the liver in order to be removed out of the body .

Newborn jaundice occurs when the liver of the baby can't break down the excess bilirubin in the blood . Jaundice have symptoms that appear on the baby and can be healed , but high levels of bilirubin can cause brain damage .

The measuring of bilirubin is made by taking blood samples from the baby , which can be painful and difficult , and the phototherapy is preformed in the hospital for several days .

This project includes two systems , a diagnostic device and a phototherapy device .

The design of an optical non-invasive device for measuring bilirubin depends on specific wavelengths that are absorbed by bilirubin , by transmitting the light beams into the tissue of the baby ,and measuring the reflection then filtering and processing the optical sensors output value , the bilirubin concentration can be determined .

The phototherapy device is designed in a matter of making the process easier , cheaper , and having high efficiency at the same time . The design is based on the mattress and blanket design .

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Chapter one

1.1 Overview

Bilirubin is a substance that exists in human blood , formed by the breaking of old red blood cells , and it gets broke down in the liver in order to remove it from the body .

Newborns are most likely to have high ratios of bilirubin , which is a condition called jaundice , this condition have many effects on the babies , like yellow skin and whites of the eye , and if not treated , it might hurt the baby and cause him much dangerous and complicated effects .

The bilirubin nowadays is measured by invasive method , which has lots of disadvantages . And its treated in the hospital by phototherapy method , which requires the baby to stay in the hospital for several days .

The idea of the project is to develop a non-invasive method that can be used by the doctor or the parents of the baby to measure bilirubin on one side , and on the other side to develop an efficient , and cheap phototherapy system that can be used at home by regular operators easily .

1.2 Motivation

After seeing the difficulties facing the doctors to measure bilirubin using invasive methods , the pain it causes to the babies , and its cost and the suffering of the parents , we saw the urge to design a non-invasive , easy , sheep , efficient and home used diagnosis and therapy for jaundice , and this was the greatest motivation for this project .

1.3 Objectives

The main objectives of this project are centered on designing and developing diagnostic and therapy devices for bilirubin with the following features :

- Measure the bilirubin concentration by non-invasive method.
- Measure the bilirubin concentration in real time.
- Making the diagnostic and therapy process easier and safer with less infection .
- Designing a system that can be home used at any time .

1.4 Importance

- The system will reduce infections drastically .
- The devices can be used easily .
- The diagnosis device will provide real time results .
- The phototherapy device will make it much easier for the parents during the therapy period .

1.5 Literature Review

Optical technique is one of non-invasive methods which can detect jaundice babies without using blood testing. Jaundice is the most common problems occurred among newborns that need special medical attention. Jaundice can cause another effect to the newborn such as brain damage which will lead to death . Therefore , a new technique that can easily detect the jaundice problem will be introduced using noninvasive technique that surely could reduce the painful compared using the old technique. By using specific wavelength of electromagnetic spectrum, bilirubin will absorb the light intensity and photodiode will capture the reflection from bilirubin. This reflection will produce a voltage value to be processed by Arduino .[1]

There was the knowledge of light transmission and absorption on a specific tissue compartment applied. The relevant skin photo-diagnostics handle 450nm - green and 575nm-blue monochromatic light. The registration of transmitted light of different frequency combinations presents the bilirubin quantity in human body by a non-invasive way. This used device was successfully tested and relevantly confronted with accurate laboratory instruments used for bilirubin measurements. The proposed device is more than ten times cheaper and easy to use. That provides reliable care after newborns within the postnatal care.[2]

Bilirubin is normally cleared from the body by hepatic conjugation with glucuronic acid and elimination in bile in the form of bilirubin glucuronides . Bilirubin absorbs light most strongly in the blue region of the spectrum near 460 nm , a region in which penetration of tissue by light increases markedly with increasing wavelength. The rate of formation of bilirubin photoproducts is highly dependent on the intensity and wavelengths of the light used , only wavelengths that penetrate tissue and are absorbed by bilirubin have a phototherapeutic effect. Taking these factors into account, lamps with output predominantly in the 460-to-490-nm blue region of the spectrum are probably the most effective for treating hyperbilirubinemia.[3]

1.6 Time schedule

Table 1. 1: Time Schedule for the summer semester 2016/2017

Week / Task	1	2	3	4	5	6	7	8	9	10
Task 1										
Task 2										
Task 3										
Task 4										
Task 5										
Task 6										

Table 1. 2: Time Schedule for the first semester 2017/2018

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Task 7	■	■	■													
Task 8		■	■	■												
Task 9				■	■	■										
Task 10						■	■	■	■							
Task 11								■	■	■	■					
Task 12										■	■	■				
Task 13											■	■	■			
Task 14													■	■		
Task 15														■	■	
Task 16															■	■
Task 17																■

- **Task 1:** Identification of Project Idea
- **Task 2:** Literature Review
- **Task 3:** Data collection
- **Task 4:** circuits Design
- **Task 5:** Documentation
- **Task 6:** Prepare the Presentation
- **Task 7:** choosing components
- **Task 8:** Editing document
- **Task 9:** Searching for components and buying them

- **Task 10:** Building circuits and PCB on simulation software
- **Task 11:** Building the phototherapy system
- **Task 12:** Printing the PCB and soldering its components on it
- **Task 13:** Testing the diagnostic device and building its box and probe
- **Task 14:** Writing the Arduino codes for both of the diagnostic and therapeutic devices
- **Task 15:** Final testing of the devices and taking results
- **Task 16:** Final editing on the document
- **Task 17:** Preparing presentation

Chapter Two

Physiological Background

2.1 Bilirubin

2.1.1 Bilirubin definition

2.1.2 Types of bilirubin

2.2 Formation and chemistry of bilirubin

2.3 Bilirubin levels

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2.3.2 Infants

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2.5.1 Urine test

2.5.2 Blood test

2.5.3 Optical bilirubin measurement

2.6 Therapy

2.1 Bilirubin

2.1.1 Bilirubin definition

Bilirubin is a brownish – yellow pigment that is contained in everyone's blood . It is formed through multi-stages by the breakdown of old red blood cells in the liver , then it is excreted into the bile duct and stored in the bladder gland . [4]

The bile is a thick liquid that helps to digest fats , so it is eventually excreted with stool (feces) , which its normal color is given by bilirubin .[5]

2.1.2 Types of bilirubin

Bilirubin circulates in the blood stream in two forms which are :

- Indirect (or unconjugated) bilirubin: This form of bilirubin does not dissolve in water (it is insoluble). Indirect bilirubin travels through the bloodstream to the liver, where it is changed into a soluble form (direct or conjugated).
- Direct (or conjugated) bilirubin: Direct bilirubin dissolves in water (it is soluble) and is made by the liver from indirect bilirubin.

2.2 Formation and chemistry of bilirubin

The average red blood cell lasts about 3-4 months in the body and then gets broken down and recycled. The deep red color of blood is due to the pigment heme, which is the main component of the protein hemoglobin.

When the hemoglobin is broken , the iron is recycled and the heme is degraded to a new compound – biliverdin – which has a green color.

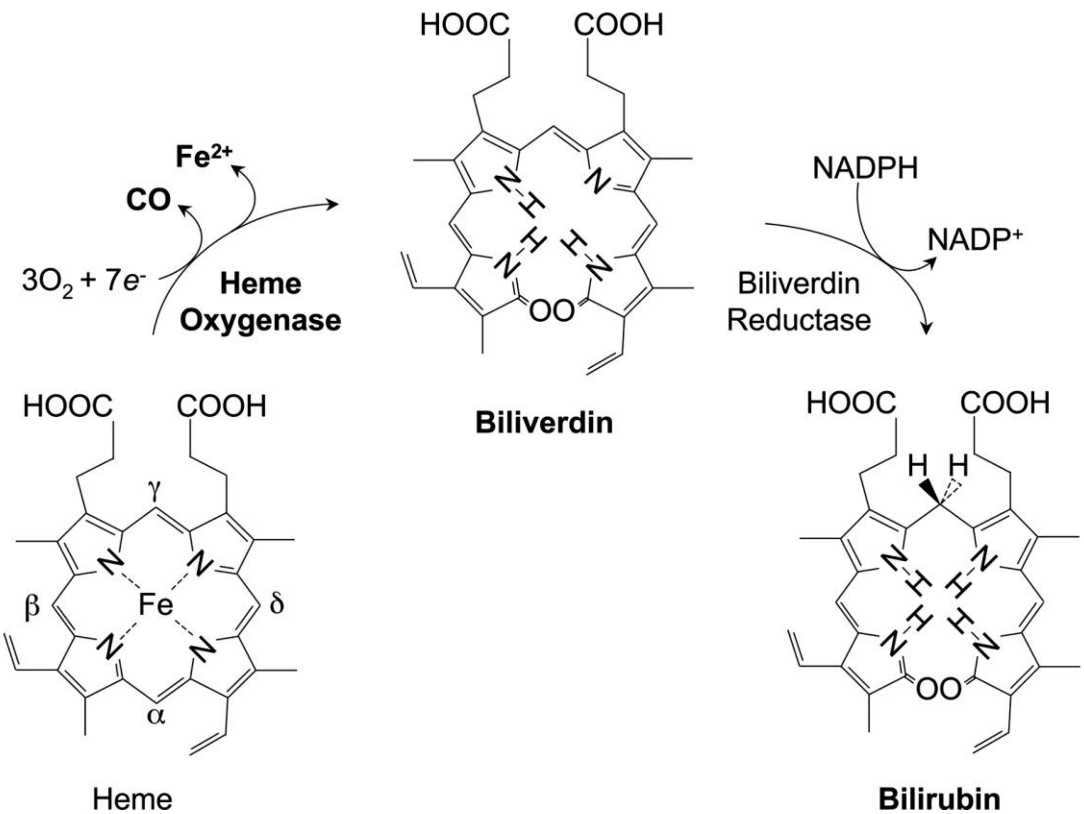


Figure2. 1: Bilirubin Chemistry

The next stage for biliverdin is converted into a yellow pigment called bilirubin , which consists of an open chain of four pyrrol-like rings (tetrapyrrol) through the action of the enzyme biliverdin reductase. [6]

2.3 Bilirubin levels

As any element in the human body , bilirubin exists in a normal range , if it exceeds that range medical treatment might be needed to prevent any life threatening complications , these ranges are as shown in the following tables .[7]

2.3.1 Adults

An adult is a human that has reached sexual maturity , mainly with age over 18 years .

Table 2. 1: the normal range of bilirubin for adults

Bilirubin type	unit	
	mg/dL	µmol/L
total	0.3 – 1.0	5.1 – 17.0
Direct	0.1 – 0.3	1.7 – 5.1
indirect	0.2 – 0.8	3.4 – 12.0

2.3.2 Infants

An infant is a new born baby . A new born may have two conditions as following .

2.3.2.1 Full-term baby

A full term baby is a baby that had a full pregnancy period of 9 months .

Table 2. 2: The normal range of bilirubin for full-term babies

age	unit	
	mg/dL	µmol/L
1 day	Less than 6.0	Less than 103
2 days	Less than 10.0	Less than 170
3 to 5 days	Less than 12.0	Less than 205
7 days	Less than 10.0	Less than 170

2.3.2.2 Premature baby

A premature is a baby that was born without completing a full pregnancy period , mostly born after 7 months of pregnancy .

Table 2. 3: The normal range of bilirubin for premature babies

age	unit	
	mg/dL	µmol/L
1 day	Less than 8.0	Less than 137
2 days	Less than 12.0	Less than 205
3 to 5 days	Less than 15.0	Less than 256
7 days	Less than 15.0	Less than 256

2.4 Hyperbilirubinemia

Sometimes the liver cannot process the bilirubin in the body because of excess bilirubin , an obstruction, or an inflamed liver . This condition is called jaundice .

2.4.1 Causes of Jaundice

This case can be caused due to several reasons as :

- Blood diseases
- Genetic syndromes
- Liver diseases, such as hepatitis or cirrhosis
- Blockage of bile ducts
- Infections
- Medicines

2.4.2 Symptoms

The jaundice symptoms of new-born baby :

- Yellow skin
- Yellow sclera (eyes)
- Sleepiness
- Poor feeding is infants
- Brown urine
- Fever
- High-pitch cry
- Vomiting

Figure2. 2: baby with jaundice

This can mean that there is damage to the liver. Testing for bilirubin in the blood is therefore a good test of damage to the liver.

Newborn infants often mild jaundice , which can either be due to normal changes in the metabolism of bilirubin or can be the first signs of a medical problem . If the level at birth is too high, the infant's bilirubin in the blood may be tested several times in the first few days of an infant's life to check that the liver is starting to work properly. Jaundice in a newborn can be very serious and life threatening if left untreated .

Other reasons for high bilirubin levels could be that more red blood cells are being destroyed than normal. This is called hemolysis .

2.5 Diagnosis

Hyperbilirubinemia can be basically diagnosed by some obvious symptoms . When the symptoms appear , some higher level tests will be performed to diagnose and rank the level of the case in order to give a suitable treatment .

Bilirubin test also might be done as a part of a group of tests to evaluate the health of liver , the most reason is to investigate jaundice is newborn . It is used also for determining if there is a blockage in the bile ducts , help detect and monitor the progress of liver diseases such as hepatits . It also help detecting increased destruction of red blood cells , and to help following how treatment is working .

2.5.1 Urine test

Urine bilirubin may also be clinically significant. Bilirubin is not normally detectable in the urine of healthy people , but if the blood level of conjugated bilirubin becomes elevated excess conjugated bilirubin is excreted in the urine , which indicates a pathological process.[8] Unconjugated bilirubin is not water-soluble and so is not excreted in the urine. Testing urine for both bilirubin and urobilinogen can help differentiate obstructive liver disease from other causes of jaundice. [9]

Figure2. 3: Urine sample with high bilirubin

2.5.2 Blood test

Blood samples tests are the most commonly used in bilirubin nowadays , it also gives the highest accuracy . In adults, blood is typically collected from a vein in the arm using a needle, but in newborns , blood is often collected from a heelstick . Heelstick is a technique that uses a small, sharp blade to cut the skin on the infant's heel so that a few drops of blood can be collected in a small tube.

Figure2. 4: Blood samples with different bilirubin concentrations

An important thing to consider when taking a blood sample for measuring bilirubin is that bilirubin is degraded by light , so, the blood collecting tubes containing blood or serum to be used for this test should be protected from illumination .

The main disadvantages or risks associated with blood tests are soreness or bruising at the site from which the blood is drawn , especially on newborn which is quite painful . In some rare cases , infections might happen , which is a life threatening risk .

Figure2. 5: Blood sample taken from new-burn’s heel stick

2.5.3 Optical bilirubin measurement

A new advanced technology is based on a field in physics called spectroscopy—measuring substances using light at varying wave lengths (visible or non-visible light). measures the level of transcutaneous bilirubin in the newborn by transmitting light at different wave lengths through the newborn’s skin and measures the intensity of those wave lengths when they come out of the skin. The amount of light absorbed by the bilirubin is calculated by comparing the intensity of the light before it enters the tissue with its intensity after it leaves. Then the transcutaneous bilirubin of the newborn is calculated according to a customized algorithm.[1]

2.6 Therapy

Near-UV LEDs are promising for destroying pathogens in blood used for transfusion .This kills pathogens , but does not damage blood plasma and platelets as long as they are not illuminated by shorter UV wavelengths. A 350 nm LEDs would kill the pathogens, control the process better, and reduce heating of the blood .

Phototherapy also extends into the visible , with blue LEDs now being used to treat jaundice in infants by breaking down a yellowish compound called bilirubin , which can accumulate to dangerous concentrations without treatment . Blue LEDs are efficient and can be matched to the 458 nm peak absorption of bilirubin , so the baby can be illuminated by blue light.[10]

Figure2.6: phototherapy of jaundice

Chapter Three

Theoretical Background

This chapter will specify the technics used for measuring and therapy of bilirubin and the parameters used for diagnosis and determining the mode of therapy we are using .

3.1 Measurement technics

In order to measure the concentration of bilirubin in blood , several methods are used , which are specified as following .

3.1.1 Spectrophotometer analysis

Spectrophotometer is a device that uses visible light and filters to get specific wavelengths to transmit it on a blood sample , with a detector to measure the light transmitted through the sample , each wavelength is used to measure a specific parameter , one of those parameters is bilirubin concentration in blood .

Bilirubin absorbs light with wavelength of 455 nm , but also there is an amount of light absorbed by oxy-hemoglobin , and for the correction of this absorbance we use another wave length of 575 nm[11] , and by comparing transmitted through a reference (blank solution) with light transmitted through the sample and using Beer-lambert law , the device determines the bilirubin concentration .

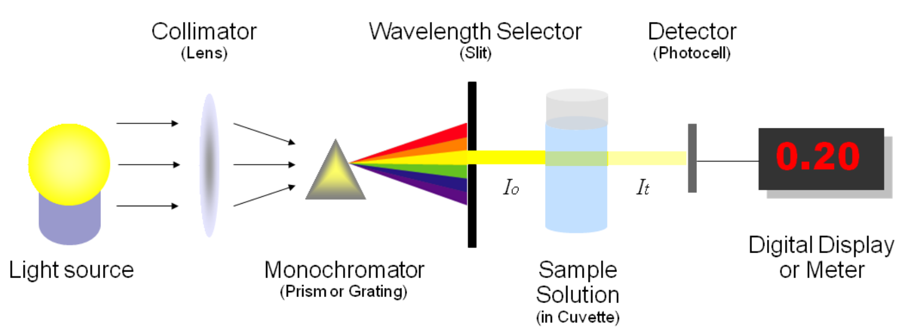


Figure 3. 1: simple block diagram for spectrophotometer

The spectrophotometer is the most common method used for measuring bilirubin concentration in blood , but it is an invasive method , which means that it uses blood samples , and that is very painful for the baby , and hard to get for the nurse or doctor , also it has a high possibility for infections . Another disadvantage of this method that it can't be done in real time , and has to be repeated every once and a wile .

3.1.1.1 Beer-Lambert Law

The Spectrophotometer uses Lambert Law to determine absorption and concentration concept of bilirubin. This concept has been used in reflection of spectrometer when the light output is less than light input [12]. It happens as the bilirubin absorbs a certain wavelength (455nm) of light and make the output become less . The absorption (A) can be calculated using Beer-Lambert's law.

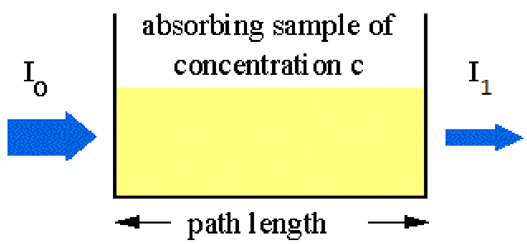


Figure 3. 2: light absorption through the sample

The transmission coefficient is given by the ratio of the transmitted intensity to the incident or initial intensity .

$$T = \frac{I1}{I0} \quad (3.1)$$

T : transmission coefficient.

I_1 : the light intensity after it passes through the sample.

I_0 : the initial light intensity before it passes through the sample.

The absorbance can be calculated through the Beer-Lambert Law:

$$A = \mathcal{E}\ \mathrm{C}\ \mathrm{L} \tag{3.2}$$

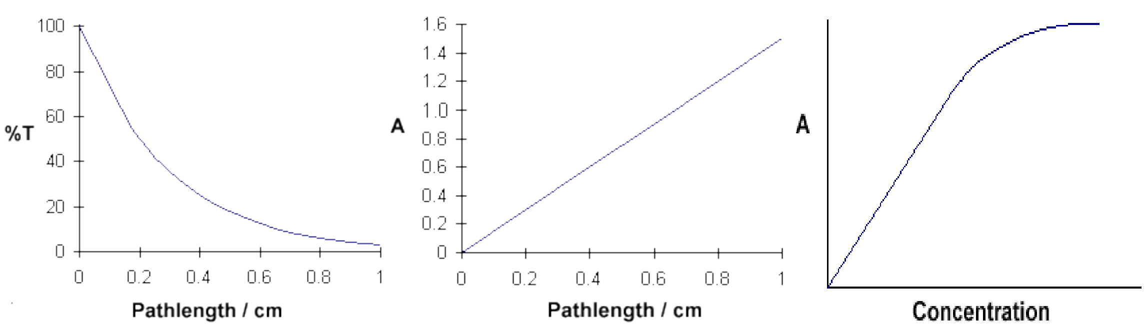
Where:

A: the absorbance of radiation by the sample.

Ɛ: the molar absorption coefficient (mol-1 cm-1).

C: the concentration of the sample (mol L-1)

L: length of solution the light passes through (cm).



(a) (b) (c)

Figure 3. 3: (a) : relation between the path length of the sample and the transmission percentage

(b) : relation between the path length of the sample and the absorption

(c) : relation between the concentration and the absorption

3.1.2 Urine test (Urinalysis)

Urinalysis is used as diagnostic tool to detect substances or cellular material in the urine associated with metabolic disorders, renal dysfunction or urinary tract infections. Often, substances will begin to appear in the urine before patients are aware that they may have a problem.[13]

The lab will supply with urine collection bags to fit into the child's diaper , but Testing bilirubin through urine may be challenging for parents of infants being tested . It also needs collecting samples for more than 24 hours , so is isn't a highly used method for testing bilirubin .

3.1.3 Optical (non-invasive) Method

A new technology is being developed for measuring Bilirubin in a non-invasive method , in order to get real time accurate readings without using samples of blood or any others , making the process much easier and more efficient . And this is the method we are working on and developing in this project .

Depending on deferent wave length lights , bilirubin is measured and monitored .

A probe holding two LED transmitters with specific wave lengths , a receiver , filtering and processing units , works as following :

- When the push button is pressed , a sequence of processes is started in order to get the ratio of bilirubin in blood
- The first LED gives 455 nm light, which is absorbed by bilirubin an oxyhemoglobin, and the reflected scatter is measured by the receiver, then filtered by low and high pass filters, to get the right frequency and to get rid of the DC part of signal made by skin and other tissue and cells of baby, then it is stored in the processing unit.
- After taking the reading from the first wavelength the other LED with 575 nm light, which is absorbed by oxyhemoglobine is used and the reflecting scatter is measured, and filtered as the previous wavelength and stored in the processing unit.

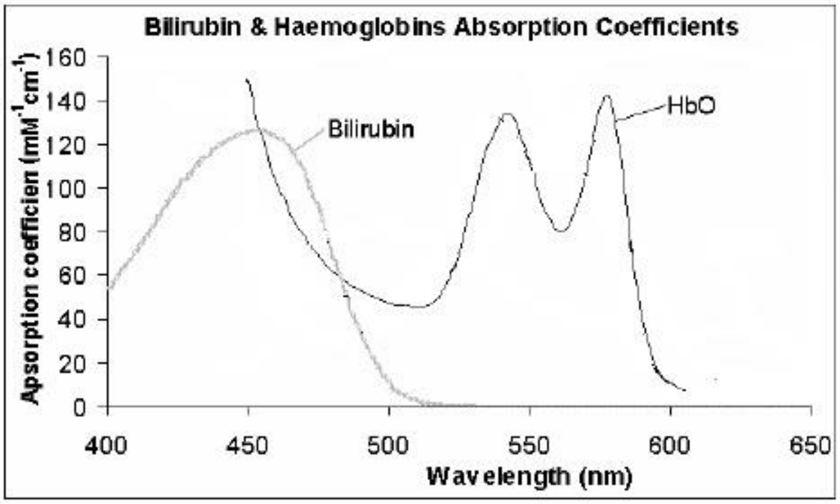


Figure 3. 4: The wave lengths absorbed by Bilirubin and Oxyhemoglobin.[14]

- The processing unit uses beer-lambert law and required equations , and by subtracting the first and second readings , and processing them , the bilirubin concentration in blood is shown on LCD screen.

3.1.3.1 Signal and processing

The signal coming out from the receiver will be formed of two parts , ac and DC voltage . The DC part is represents the reflection by venous blood and tissues , where the ac represents the reflection of light when the attenuation of light is caused by arterial blood .

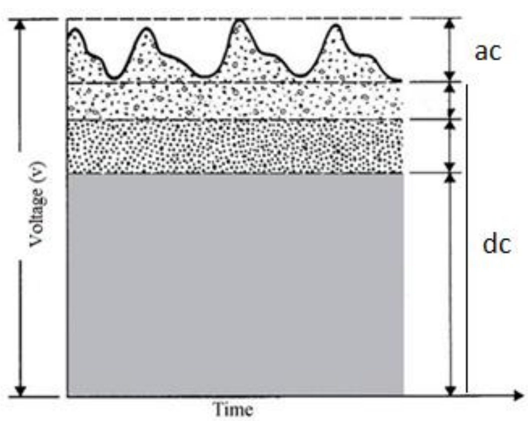


Figure 3. 5: the output signal from the receiver divided into ac and DC voltages

In order to get a clear signal representing the bilirubin in blood stream , the DC part should be suppressed , and that is made by the high pass filter

Table 3. 1: Voltage average reflection absorption of skin bilirubin concentration.[2]

Concentration bilirubin calibrator (mg/dL)	Voltage average reflection absorption (V)
1-4	2.37 – 2.1
7-10	1.78-1.53
15-20	1.43-1.06

Beer's law assumes no refraction of light, so the absorption determined by logarithm of ratio transmission light to the Inlet light. Since the jaundice starts on the head and the light can not pass through this region, we assumed the absorption is determined by reflection light and inlet light.

So, the reflection coefficient is given by the ratio of the reflective intensity to the incident or initial intensity.

$$R = \frac{Iref}{I0} \tag{3.3}$$

The relation between A and R is:

$$A = -\log\left(\frac{Iref}{I0} \right) \tag{3.4}$$

Now by using beer's lambert law for relationship between absorbance, path length of light and concentration we can calculate the concentration of bilirubin.

$$A = \mathcal{E}\, \mathrm{C}\, \mathrm{L} \tag{3.1}$$

Where:

Ɛ: the molar absorption coefficient of bilirubin (55000 cm^{-1}/M).

L: length of skin that light passes through (cm).Which differs from person to another.

3.1.3.2 Kramer's rule

The level of jaundice by simply observing the baby's skin color, can utilize the cephalocaudal progression of jaundice. Kramer drew to the jaundice starts on the head, and extends towards the feet as the level rises. This is useful in deciding whether or not a baby needs to have the total bilirubin measured [15]. Kramer divided the infant into 5 zones as show in Fig.(3.6) the total bilirubin range associated with progression to the zones is as follows in table(3.2) .[16]

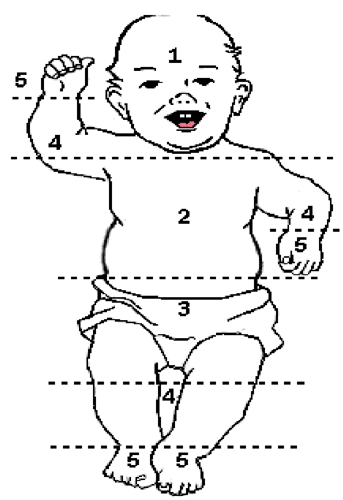


Figure 3. 6: Kramer's division of the body

Table 3. 2: Correlation between dermal zones and serum bilirubin values.

Zone	Definition	Total bilirubin (µmol/L)
1	Head and neck	101±5
2	Upper trunk	152 ± 29
3	Lower trunk and thighs	201 ± 31
4	Arms and lower legs	257 ± 29
5	Palms and soles	>250

3.2 Jaundice therapy

Jaundice can lead to serious complications , such as brain damage , and death , so the treatment is necessary to be done .

3.2.1 Therapy Methods

In therapy there are more than one method used , but the only one method is used more than the others .

3.2.1.1 Intravenous immunoglobulin (IVIg)

Jaundice may be related to blood type differences between mother and baby. This condition results in the baby carrying antibodies from the mother that contribute to the breakdown of blood cells in the baby. Intravenous transfusion of an immunoglobulin — a blood protein that can reduce levels of antibodies — may decrease jaundice and lessen the need for an exchange blood transfusion.

Common side effects include pain at the site of injection, muscle pain, and allergic reactions. Other severe side effects include kidney problems, anaphylaxis, blood clots, and red blood cell breakdown.[17]

3.2.1.2 Exchange transfusion.

When severe jaundice doesn't respond to other treatments, a baby may need an exchange transfusion of blood. This involves repeatedly withdrawing small amounts of blood, diluting the bilirubin and maternal antibodies, and then transferring blood back into the baby — a procedure that's performed in a newborn intensive care unit.

3.2.1.3 Phototherapy

Phototherapy (light therapy) is the most common medical treatment for jaundice in newborns. In most cases, phototherapy is the only treatment required. It consists of exposing an infant's skin to light, which breaks bilirubin down into parts that are easier to eliminate in the stool and urine. Treatment with phototherapy involves using special lights, blue light and ultraviolet light. During treatment, your baby will wear only a diaper and protective eye patches.

Phototherapy or light therapy, involves exposing the skin to light on a regular basis and under medical supervision. Treatments are done in a doctor's office or psoriasis clinic or at home with phototherapy unit.

3.2.1.3.1 Main types of phototherapy

The standard form of phototherapy, the baby lies in a bassinet or enclosed plastic crib (incubator) and is exposed to a type of fluorescent light or LED light that are absorbed by baby's skin. During this process, the bilirubin in the baby's body is changed into another form that can be more easily excreted in the stool and urine.

In older phototherapy systems ultra-violet light was used, but it had too many risks and was found to be less efficient than the blue light (455 nm). The risks involved with overexposure to

UV radiation has been linked to many negative health effects, such as skin burns, premature skin aging, skin cancer, eye damage and weakening of the immune system .

In modern phototherapy units Light Emitting diodes (LED) are used due to their advantages which include low power consumption, low heat production, and a much longer life span of the light-emitting units compared with other light sources.

Blue light in the range of 450-490 nm is most effective for phototherapy. The absorption of light by the normal bilirubin generates configuration isomers, structural isomers, and photo-oxidation products. The two principal photo-isomers formed in human's body are shown in figure (3.7).

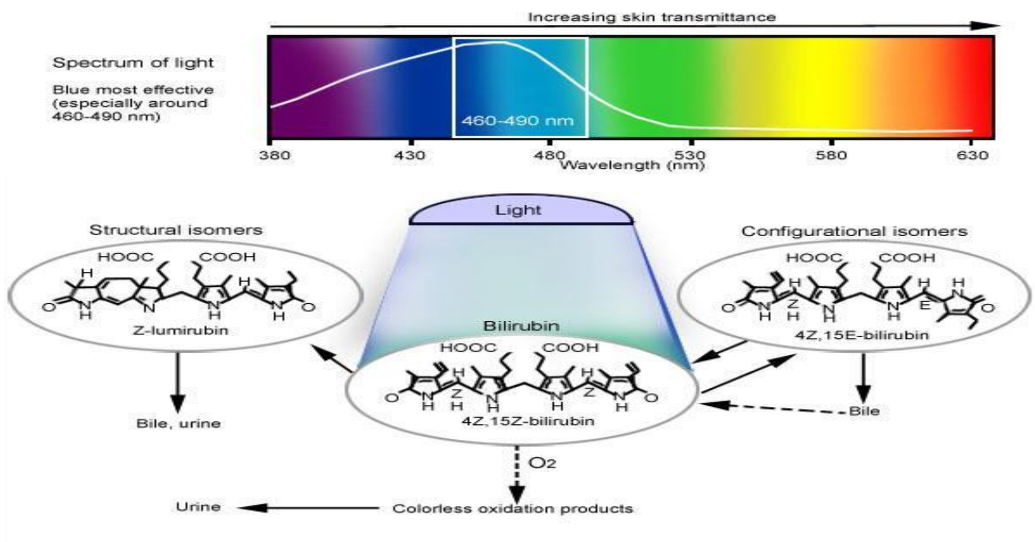


Figure 3. 7: principal photo-isomers formed in human's body.

Configurational isomerization is reversible and much faster than structural isomerization. Structural isomerization is slow and irreversible. Photo-oxidation occurs more slowly than both configurational and structural isomerization. Photo-oxidation products are excreted mainly in urine.[18]

The phototherapy used nowadays can be sorted into 3 types :

- **Conventional phototherapy :**

  Where your baby is laid under a halogen or fluorescent lamp with their eyes covered .

- **Light Emitting Diodes** :

  Which are explained previously .

- **Fiber-optic phototherapy :**

  Where your baby lies on a blanket that incorporates fiber-optic cables; light travels through the fiber-optic cables and shines on to your baby's back

3.2.1.3.2 Factors affecting phototherapy

The efficiency of bilirubin phototherapy is mainly affected by many factors , as :

- **Lamps life :**

  Lamps has a default age, mainly around 1000 hours of use in florescent and halogen , and around 20000 hours in LEDs , after that the lamps gets to be less efficient and might have problems like giving a wrong wave length of given light .

- **Distance from the light source :**

  Ideally (5 – 10) cm [3] , The more the distance, the less is the light energy hitting the body surface.

- **Skin exposure to light :**

  Not less than 40% of body surface has to be exposed to light .[3]

- **Surface of the skin exposed/body weight ratio .**
- **Pigmentation ratio .**
- **Duration of the exposure :**

The effectiveness of phototherapy is to some extent proportional to the phototherapy time .

- **Use of reflective surfaces around the bed and white sheets to reduce absorption .**

Chapter Four

Design

4.1 diagnostic System

4.1.1 System Block-diagram

4.1.1.1 LEDs

4.1.1.2 Detector

4.1.1.3 Operational Amplifier

4.1.1.4 High Pass Filter

4.1.1.5 Low Pass Filter

4.1.1.6 Inverting Amplifier

4.1.1.7 Microcontroller

4.1.1.8 Power suppliers

4.2 Phototherapy system

4.2.1 System Block-diagram

4.2.1.1 Microcontroller

4.2.1.2 Switching transistor

4.2.1.3 Power Diodes

4.2.1.4 Fuse

4.2.1.5 LEDs

4.2.1.6 Power Supply

4.2.1.7 Voltage Regulator

4.2.1.8 Mattress And Blanket

4.2.1.8.1 Mattress

4.2.1.8.2 Blanket

4.2.1.8.3 Calculations and Connection

This chapter will demonstrate the system components , the connections and calculations for measurement and phototherapy systems .

4.1 diagnostic System

The measurement system is the optical diagnosis system we are developing in this project . The system is based on light emitters , a receiver , and processing unit , with all their driving circuits and connections .

4.1.1 System Block-diagram

The system will be based as the following block-diagram .

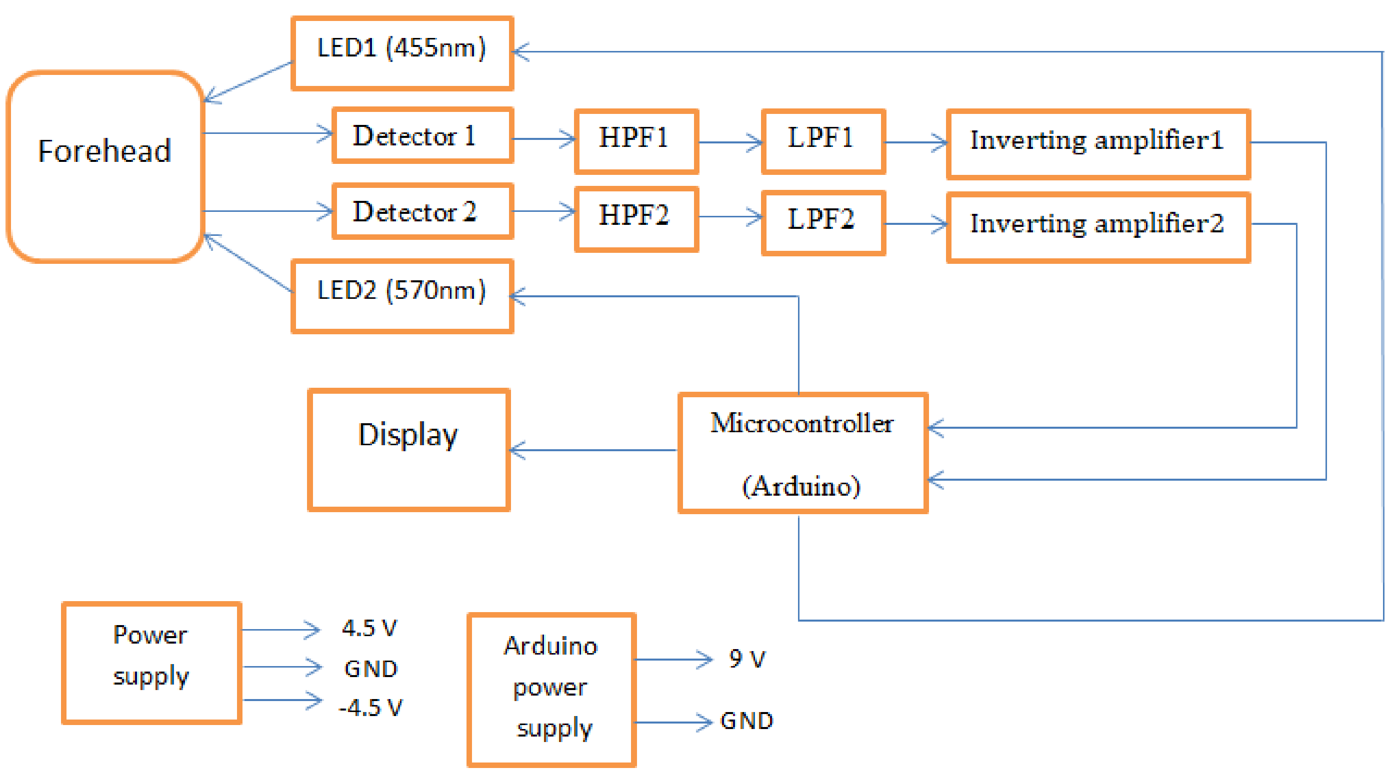
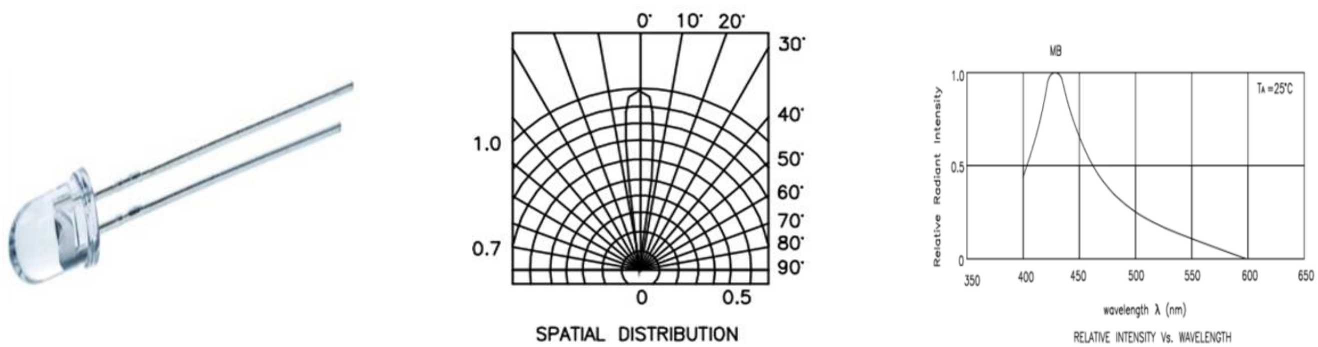


Figure 4. 1: Block diagram of bilirubin concentration measurement

4.1.1.1 LEDs

Blue light and green light with wavelengths of 455 nm and 570 nm respectively were chosen. The wavelength of 455 nm is the absorption maximum of bilirubin and oxyhemoglobin , and the wavelength of 570 nm is to get oxyhemoglobin concentration for the calculations .

The blue LED (L-53MBC) at wavelength of 455 nm with viewing angle of 16 ° is chosen to get bilirubin and oxyhemoglobin concentration . Fig. (4.2) depict the LED that used and its specification.



(a) (b) (c)

Figure 4. 2 (a) Blue LED (455 nm)L-53MBC
(b) Viewing angle for (455nm) LED
(c) Relative intensity Vs. wavelength

The driving circuit is made to provide the 455 nm LED with power from the arduino output (5V) and the transistor is used as a switch controlled by a digital pin from arduino , and a 100 ohm resistor was used on the collector to give the LED 20 mA (forward current of 455nm LED) , as shown in figure(4.3).

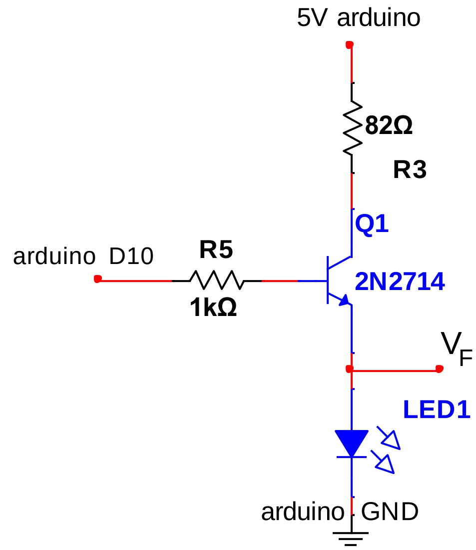


Figure 4.3: Driving circuit for Blue LED (455 nm)

To maintain the forward current 20mA and forward voltage 3.4 V, the resistor R1 calculate by equation (4.1).

$I_F = 20$ mA

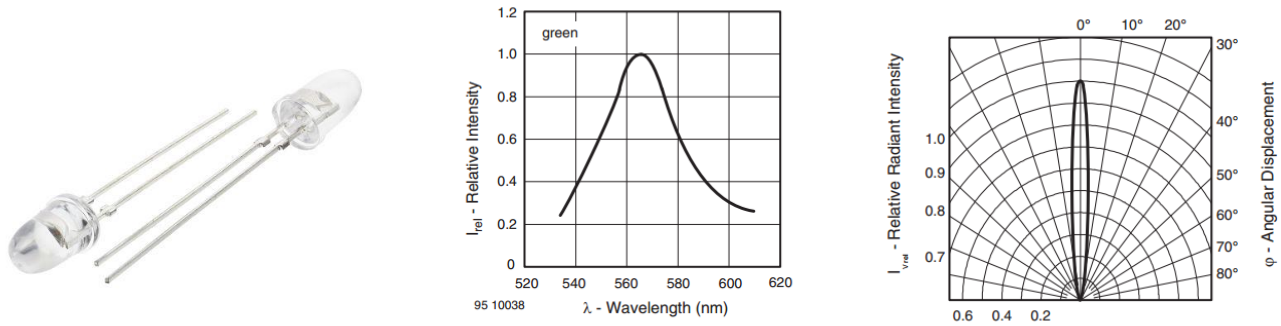
$V_F = 3.4$ V

$$R3 = \frac{\mathrm{Vcc-VF}}{I} \tag{4.1}$$

So

$$\mathrm{R3} = \frac{(5 - 3.4)}{20\mathrm{mA}} = 82\ \Omega$$

The green LED (TLHG5800) at 570 nm with viewing angle of 8° is chosen to get oxyhemoglobin concentration. Figure (4.4) depict the LED that used and its specification.



(a) (b) (c)

Figure 4. 4: (a) Green LED (570 nm) TLHG5800
(b) Relative intensity Vs. wavelength
(c) View ing angle for Blue LED (570nm)

The driving circuit is made to provide the 570 nm LED with power from the arduino output (5V) and the transistor is used as a switch controlled by a digital pin from arduino, as shown in figure(4.5).

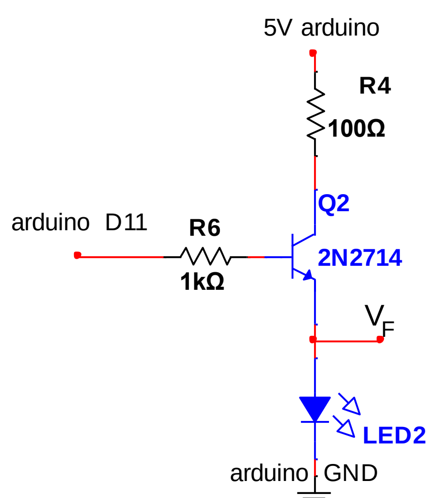


Figure 4. 5 : Driving circuit for Gerrn LED (570 nm)

To maintain the forward current 20mA andfoward voltage 3V, the resistor R4 is calculated by equation (4.1).

I_F = 20 mA

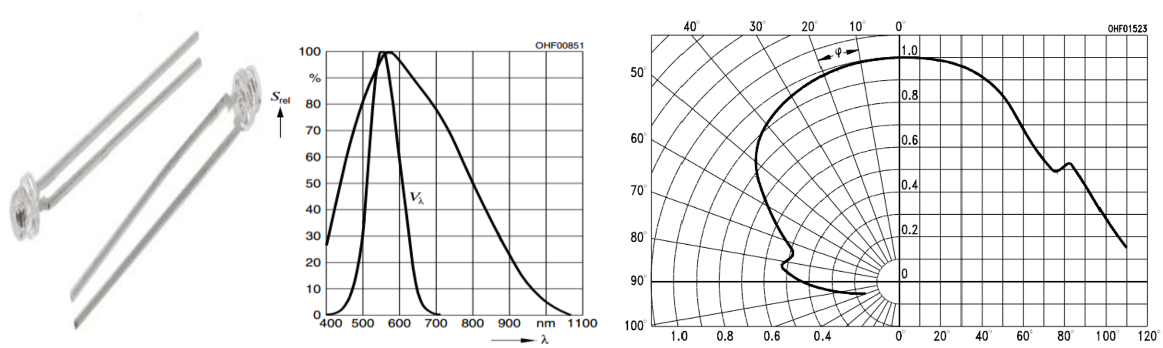
V_F = 3 V

$$R4 = \frac{(5-3)}{20\text{mA}} = 100\ \Omega$$

The microcontroller will take signal from a push button in order to activate the digital pins controlling the driving circuits for a controlled time period (250ms) which is enough time for the detector to take signal and pass it through next components to be processed.

4.1.1.2 Optical Detector

The phototransistor SFH 3310 were used, with special response range (350-940) nm and peak sensitivity 570nm. Figure (4.6) depict the phototransistor SFH 3310 that we will use and its specification.



(a) (b) (c)

Figure 4.6: (a) The phototransistor SFH 3310 specification
(b) The relative sensitivity of phototransistor SFH 3310
(c) Viewing angle of phototransistor SFH 3310

Two phototransistor used to detect both of the wavelengths, each one when triggered, then the signal from the detector will be filtered and amplified, then sent to the microcontroller.

The phototransistor generate voltage when it exposed to light, each LED has a detector, the voltage from the detectors represent the light that reflection from the skin of baby. Figure (4.7) shows the phototransistor SFH3310.

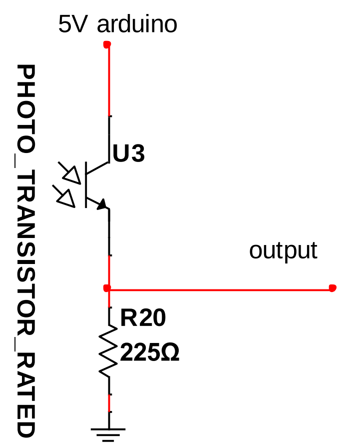


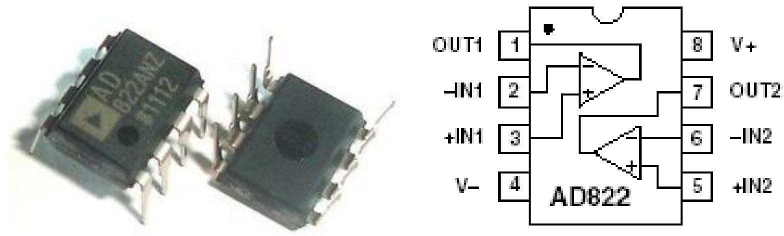
Figure 4.7: phototransistor driving circuit for detection 455n and 570 nm

To maintain the forward current 20 mA, the resistor R20 is calculated by equation (4.1)

$$\mathrm{R20} = \frac{(5 - 0.5)}{20\mathrm{mA}} = 225\ \Omega$$

4.1.1.3 AD822ANZ Operational Amplifier

For this project, AD822ANZ was used, since it is a rail to rail amplifier, can be used as single or dual supply amplifier, have a high CMMR of 80dB and a very good Ac and DC performance. And the type ANZ is used because it has long standing pins, making dealing with it easier.



(a) (b)

Figure 4. 8: (a) AD822ANZ Operational Amplifier
(b) Internal connection of AD822AN

4.1.1.4 High Pass Filter

The high pass filter suppresses signals with lower frequency than the desired frequency range. The high pass filter will essentially allow high frequency signals , also it will remove the DC signals representing any other tissue than the blood .

The high-pass filter that are used is a second order Butterworth High-Pass Filter. the cutoff frequency (f_C) is set at 0.5Hz, as shown in figure (4.9).

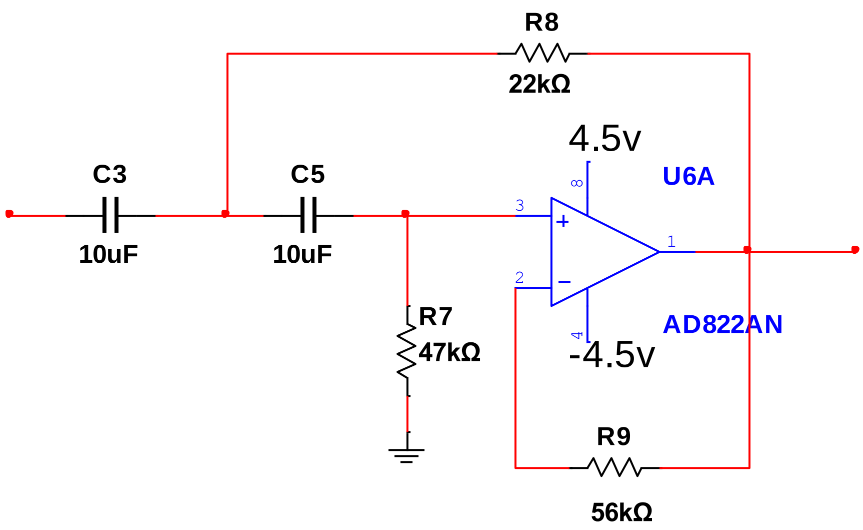


Figure 4.9: Second order HPF1and HPF2.

We can set fc by equation (4.2), at low frequency , C3 and C5 act as open circuit .

$$fc = \frac{1}{2\pi\sqrt{(C3C5R7R8)}} \tag{4.2}$$

But we must consider that the quality factor Q must be as close as possible to 0.707 according to equation (4.3) to make the output signal flat, and the filter will be a Butterworth Sallen-key filter.

$$Q = \frac{1}{2}\sqrt{\frac{R7}{R8}} \tag{4.3}$$

Let C3 = C5 = 10µF and R7 ,R8 by the equations (4.2) and (4.3) become:

R7 = 47KΩ

R8 = 22KΩ

The gain of second order HPF is 1 , and can be calculate through equation (4.4).

$$Gain = 1 + \frac{R9}{R\infty} \tag{4.4}$$

We removed R_∞ so that it will be ∞ , and the gain = 1 .

The high pass filter should give output characteristics for (fc = 0.5Hz) as shown in figure (4.10) , where Y-axis represents the amplitude in dB , and X-axis represents frequency .

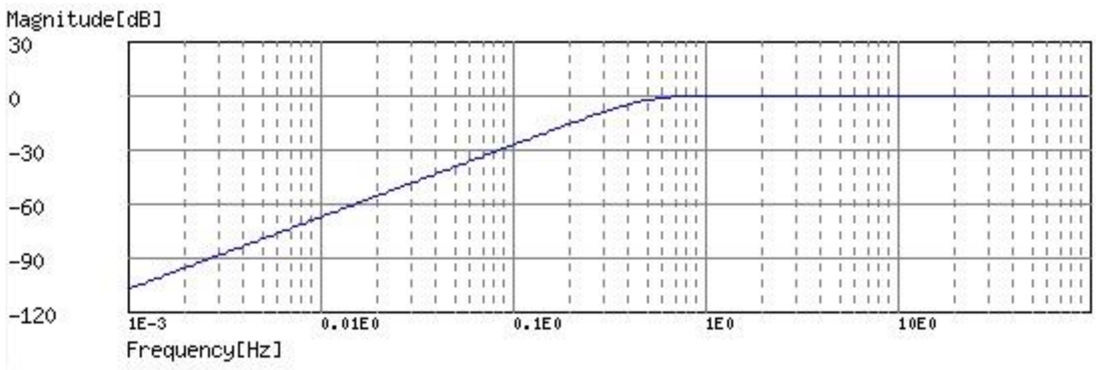


Figure 4. 10: Output Characteristics for the HPF

4.1.1.5 Low Pass Filter

The low pass filter enables us to filter out unwanted signals with higher frequency than the desired frequency range . The low pass filter will essentially allow low frequency signals from 0Hz to the cut-off frequency, while blocking any higher frequencies.

The Low-pass filter that are used is a second order Butterworth Low-Pass Filter. The cutoff frequency (f_C) is set at 40Hz, as the circuit shown in figure (4.11).

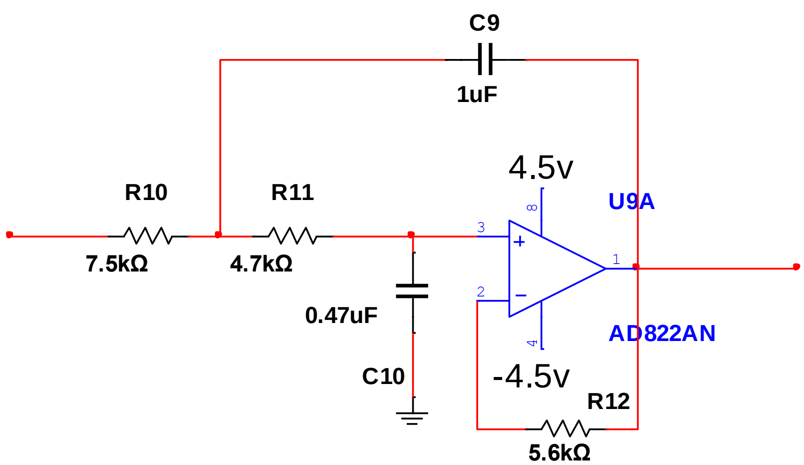


Figure 4.11: second order LPF1and LPF2.

We can set fc by equations (4.2) and (4.4) where Q must be as close as possible to 0.707 to make the output signal flat and make it a Butterworth filter , at high frequency, C1 and C2 act as short circuit .

$$fc = \frac{1}{2\pi\sqrt{(C9C10R10R11)}} \tag{4.2}$$

$$Q = \frac{1}{2}\sqrt{\frac{C9}{C10}} \tag{4.4}$$

From equations (4.2) and (4.4) we find :

C9 = 1µF

C10 = 0.47 µF

R10 = 7.5KΩ

R11 = 4.7KΩ

The gain of second order LPF is 1 , and can be calculate through equation (4.4).

$$Gain = 1 + \frac{R12}{R\infty} \tag{4.4}$$

We removed R_∞ so that it will be ∞ , and the gain = 1 .

The low pass filter should give output characteristics for (fc = 40Hz) as shown in figure (4.12) , where Y-axis represents amplitude in dB , and X-axis represents frequency .

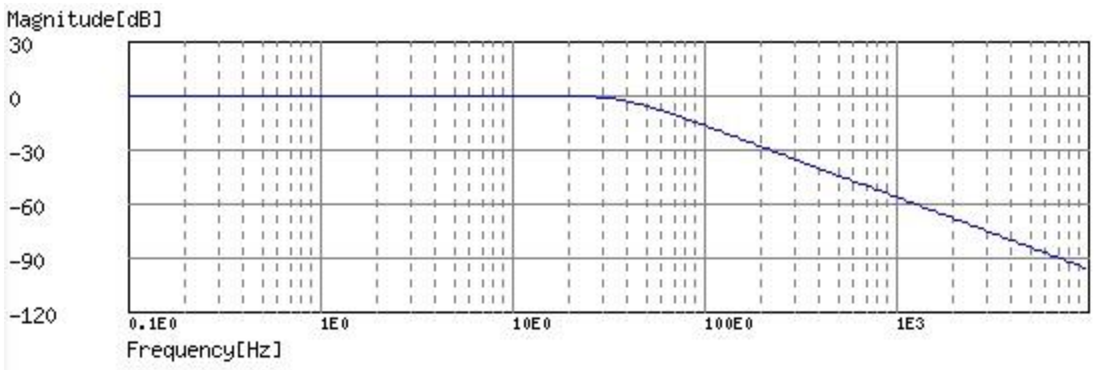


Figure 4.12: Output characteristics for the LPF.

4.1.1.6 Inverting amplifier

Gain amplifier is an inverting operational amplifier which is used to amplify the signal for the next stage and flipping its sign from negative to positive by using equation (4.5) as shown in the figure (4.13).

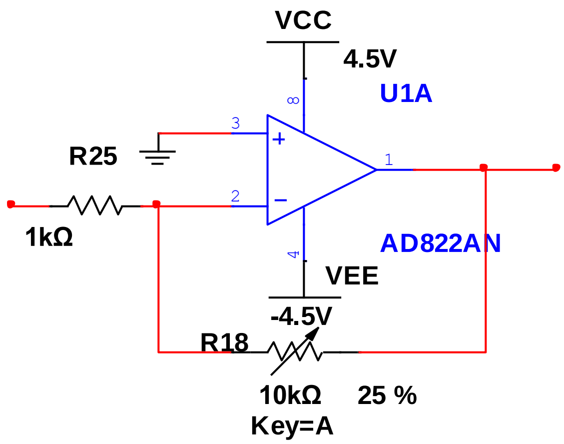


Figure 4.13: Gain amplifier circuit

$$Gain = -\frac{R18}{R25} \tag{4.4}$$

To control of gain we will use R25= 1KΩ and R18 as a variable resistance to make the signal suitable for processing in the next stage (microcontroller).

4.1.1.7 Microcontroller

The microcontroller is used to control the operating of LED1and LED2 , receive signal from the filtering circuit and process it , and then display the result on an LCD screen .

For this project we are using Arduino Nano (Figure 4.14) as a microprocessor for its small size mainly.

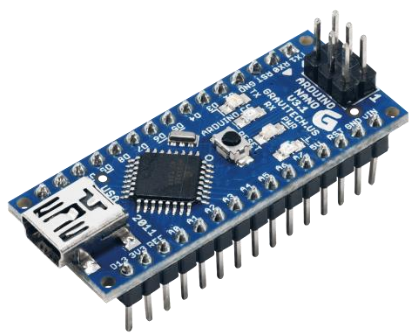


Figure 4.14: Arduino Nano .

The result of the bilirubin concentration test will be displayed by the arduino on an LCD screen .

Figure 4.15: LCD screen

4.1.1.8 Power suppliers

In this project two power supplies were used , consisting of two 9V batteries , as described bellow .

The microcontroller used in the project requires 7 to 12 DC volts , so we are using a 9V DC heavy duty battery .

Another DC 9V heavy duty battery is used to supply the IC's used in the project with positive and negative Vcc , by dividing the 9V into (4.5V) and (-4.5V) using the circuit shown in figure (4.16) . A mid-range resistors (100k ohm) were used in order to decrease current dissipation in them and not having a bulk tolerance at the same time.

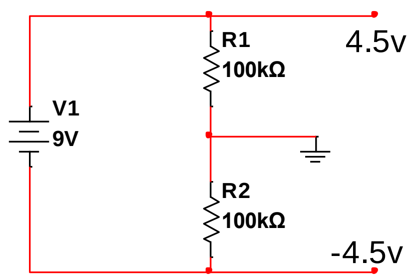


Figure 4.16: Power supply driving circuit.

4.2 Phototherapy system

One of the biggest aims of this project is to make the phototherapy home used in a high efficiency.

After studying the problem and the project , it was found that the most optimum design was the mattress and blanket design . The mattress and blanket platform offers intensive LED phototherapy at its finest . Its soft and flexible design allows for it to be positioned beneath and above the baby to deliver photography with a blue LED light source. It utilize blue LED technology in a safe manner and reduces the potential risk of skin damage , and by using LEDs , the surface area that is covered is going to be larger than the area covered using fiber optics .

4.2.1 Phototherapy system block diagram

The system will be based on the following block diagram

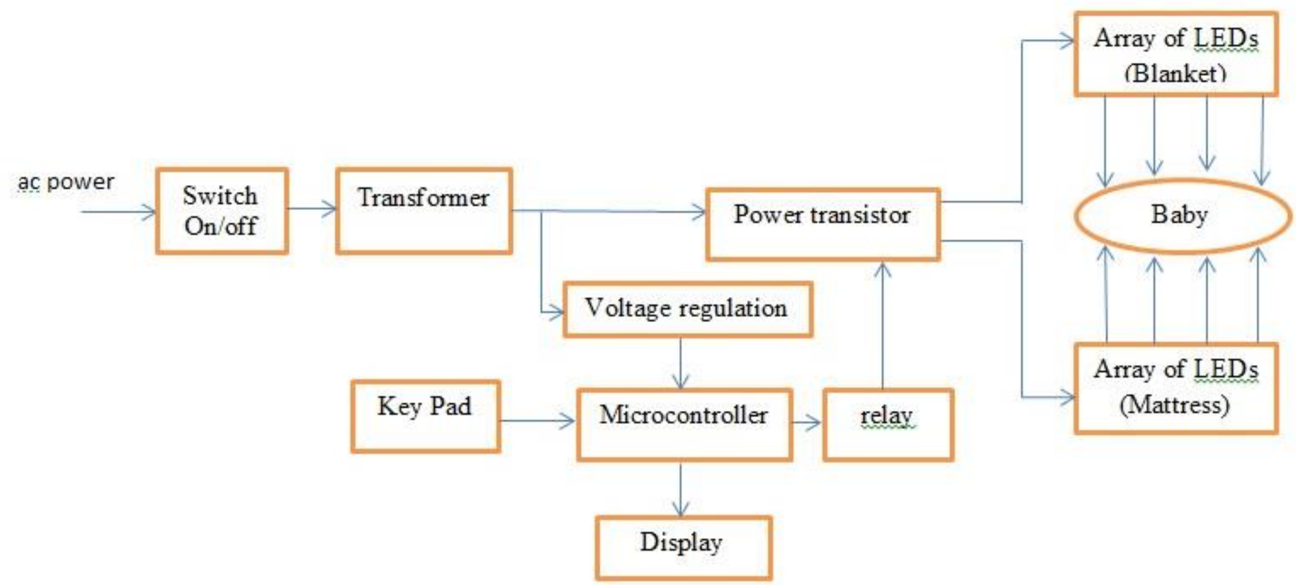


Figure 4. 17: Phototherapy system Block Diagram

4.2.1.1 Microcontroller

The microcontroller is used in this system to control the operating of the device. The microcontroller that will be used is Arduino Uno. Figure (4.18) .

Figure 4. 18 : Arduino Uno

The time control and process of system will be displayed by the arduino on an LCD screen as session time and count down timer until session over.

Figure 4. 19: LCD screen

The key pad connected to the arduino will be the input device for the system. It will be used to inter the phototherapy session time by entering time in minutes of two digits.

The keys from 0 to 9 are used to enter the time, the time is limited by 99 minute, the key (#) used to start the session time and (*) to restart.

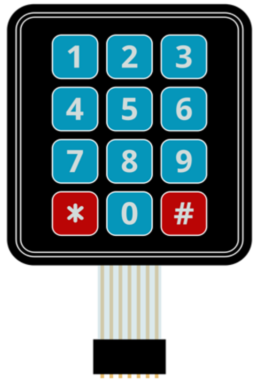


Figure 4. 20 : Key Pad

The relay is used to control the 12V power flow to the system components by the 5V arduino digital output .

Figure 4. 21 : Arduino relay

4.2.1.2 Switching transistor

In order to power the LED arrays, a relatively high current is required for that , so a power transistor (TIP122) is used as a switch which can handle up to 4A . Figure (4.22).

Figure 4. 22: TIP122 Power Transistor .

When a high current passes through the transistor its heat rises , so a heat sink is used to keep it cool . figure (4.23) .

Figure 4. 23 : Thermal heat sink used for TIP122

The TIP122 will be used as a switch with a 2K ohm on the base to limit the base current from flowing to the emitter , and it will be controlled by the relay connected to the base , as shown in the figure bellow .

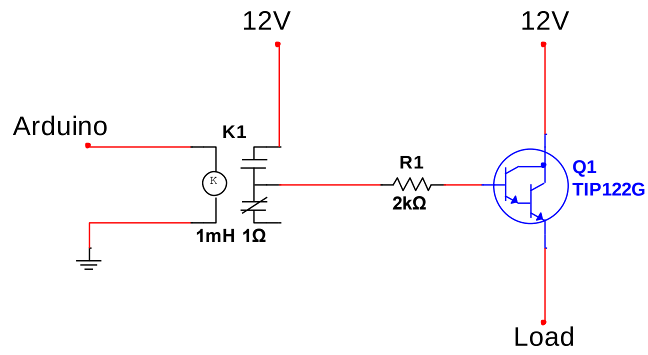


Figure 4. 24: TIP122 Connection Circuit

4.2.1.3 Power Diodes

As will be shown in calculations and connection section , the voltage passing must be decreased by 1.4V , so 2 power diodes are used in series with the TIP122 emitter , each of them cuts of 0.7V

4.2.1.4 Fuse

For the protection of the phototherapy LEDs used , a fuse of 1A , which is a little bit higher than the required current for the operating , is implemented before the load .

4.2.1.5 LEDs

Phototherapy is made by using light with wavelength of (450nm – 490nm) , in this project , 455nm LEDs are used , which are the same as the 455nm LEDs used in optical diagnosis that are mentioned previously . Each LED operates on 3.2 – 3.4 V , 20mA .

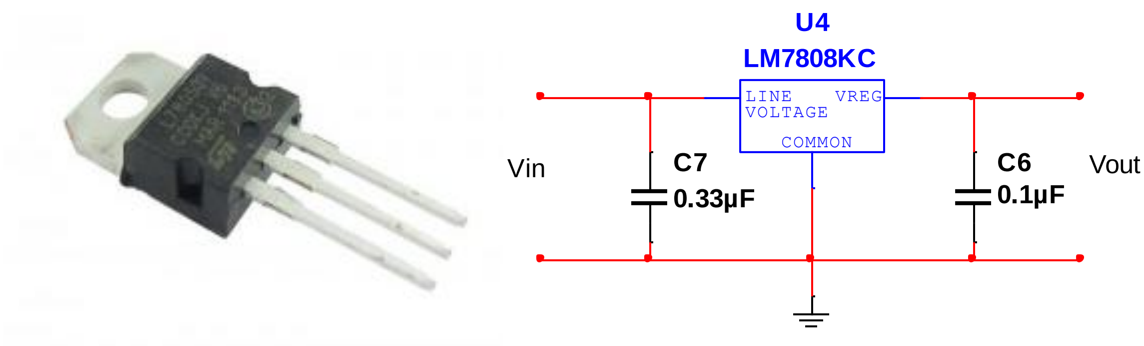
4.2.1.6 Power Supply

The phototherapy system is powered by a 12V/2A transformer in order to preform optimally as will be shown in calculations later ..

Figure 4. 25: 12V DC wall adapter.

4.2.1.7 Voltage Regulator

The microcontroller operates on 7V – 12V DC , so we used the LM7808 voltage regulator (figure 4.26 – a) to give a med range voltage of 8V for the microcontroller , its connection is taken from the datasheet , as shown in figure (4.26 – b) .



(a) (b)

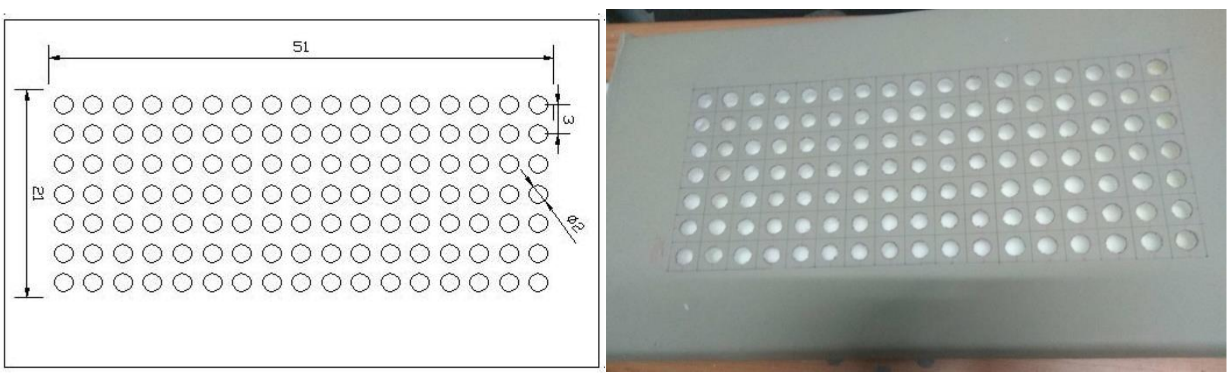
Figure 4. 26: (a) LM7808 voltage regulator
(b) LM7808 circuit

4.2.1.8 Mattress And Blanket

The mattress and the blanket will represent the phototherapy system , because the LEDs will be placed is them properly in such a way that the baby lies between them and get exposed to the blue light .

4.2.1.8.1 Mattress

The mattress will have a matrix of holes , which LEDs will be placed in as shown in figure (27) .



(a) (b)

Figure 4. 27 (a): the sketch of the mattress showing the LED holes in it .
(b): The mattress after making the LED holes in it.

The mattress used is a medical mattress, made of compressed sponge, which is very suitable for the purpose of use.

The mattress has 120 LEDs inside it, 119 forming the LEDs array , and a hidden LED for compensating the LED groups made of 3 LEDs for each group , as will be demonstrated in the calculation and connection section .

4.2.1.8.2 Blanket

The blanket used is a regular baby blanket with its lower side modified such that its relatively light transparent , and the LEDs will be inside it facing the infants body .

The blanket has 27 LEDs arranged inside it in a proper way such that the LEDs array will cover the chest and belly of the baby . figure (4.28).

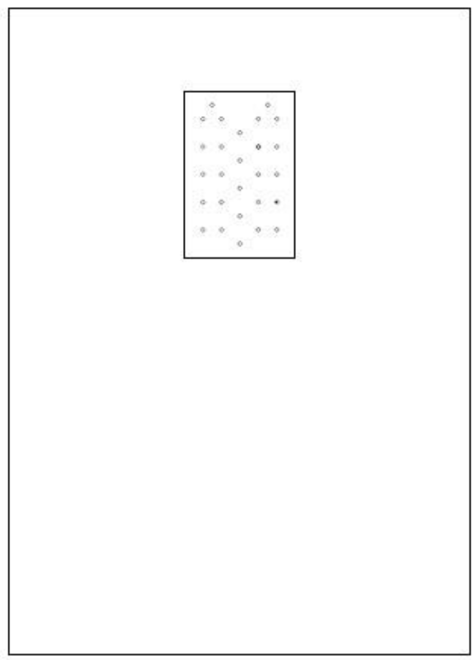


Figure 4.28: A sketch of the mattress showing the LED holes in it .

4.2. 1.8.3 Calculations and Connection

As said earlier , each LED must be supplied with 3.2V - 3.4V / 20mA , and a 12V/2A power supply is used , also some considerations must be taken , as shown bellow .

The TIP122 transistor cuts 1.4V , so we get :

$$12V - 1.4V = 10.6V$$

So 3 LEDs at most can be connected in series .

$$3 * 3.2 = 9.6V$$

The voltage must be lowered by around 1V , so 2 power diodes are connected in series before the load , which makes the output voltage equal around 9.2V .

By dividing the LEDs into 3-LEDs blocks , we get for the mattress :

$$120 / 3 = 40 \text{ blocks}$$

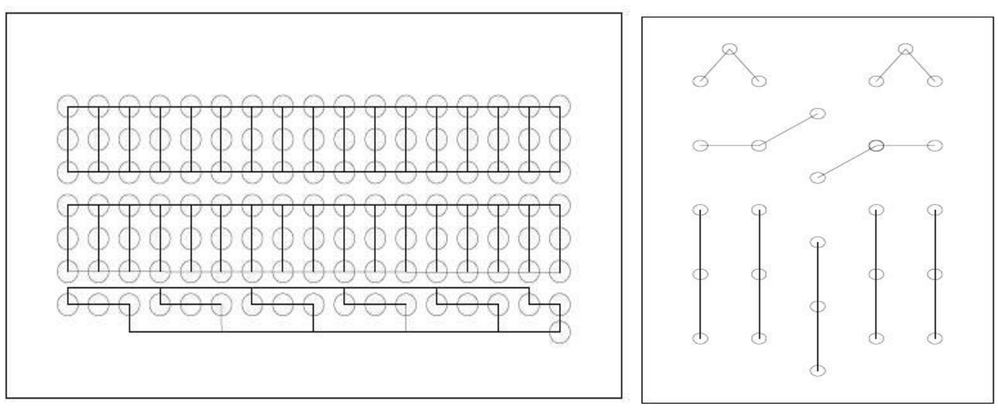
For the blanket :

$$27 / 3 = 7 \text{ blocks}$$

The total number is 47 blocks , each requires 20mA , so the total current required is :

$$20mA * 47 = 940mA$$

The connections of the mattress and blanket are as shown in the following figures .



(a) (b)

Figure 4.29: (a) The internal connection for the mattress LED
(b) The internal connection for the blanket LED

Chapter Five

System Building and Results

5.1 Diagnostic System

The diagnostic system’s main functionality is to give the bilirubin concentration in the blood , as reading shown on the device’s LCD screen .

5.1.1 System Circuit Connections and PCB

In order to reduce noise as much as possible , and to make it compact design , the system main board was printed as PCB , and the layer was as shown in figure (5.1).

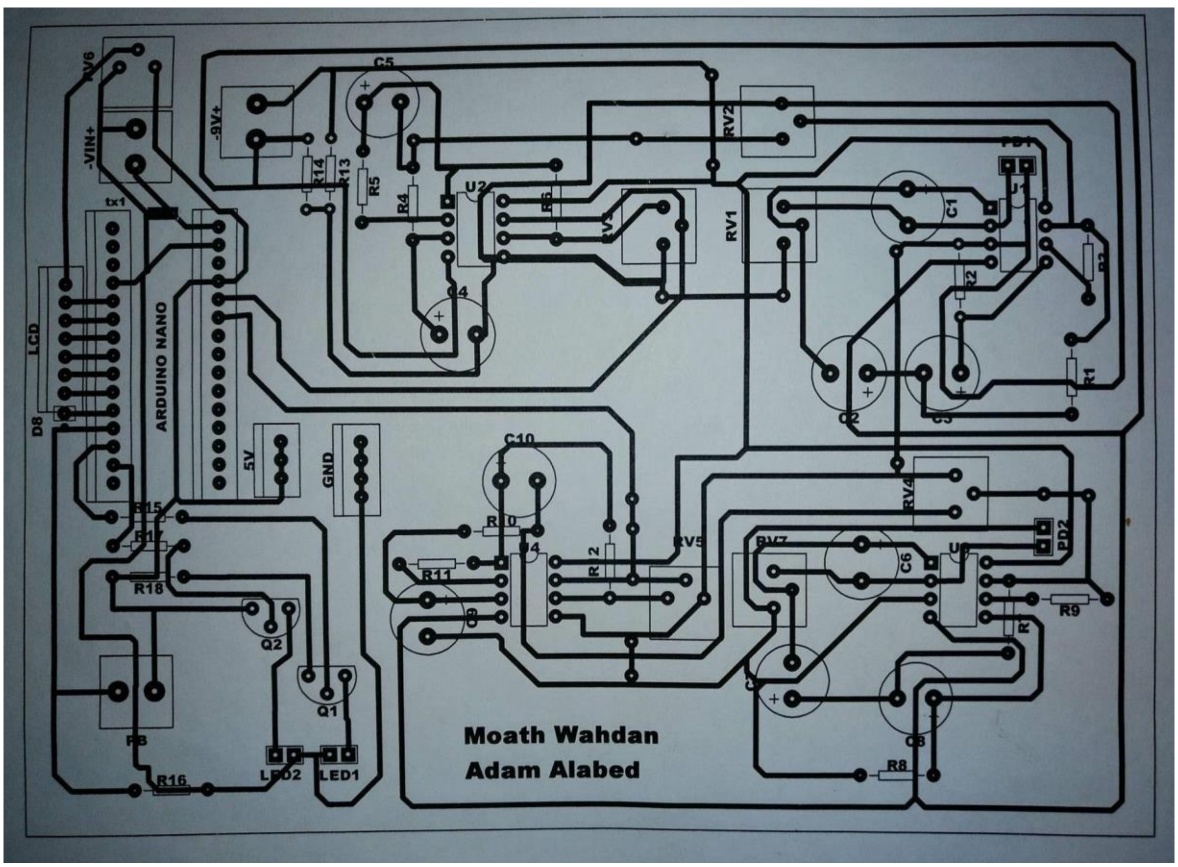


Figure 5. 1 :PCB layer for the diagnostic system

After printing the circuits , the final result was as shown in figure (5.2).

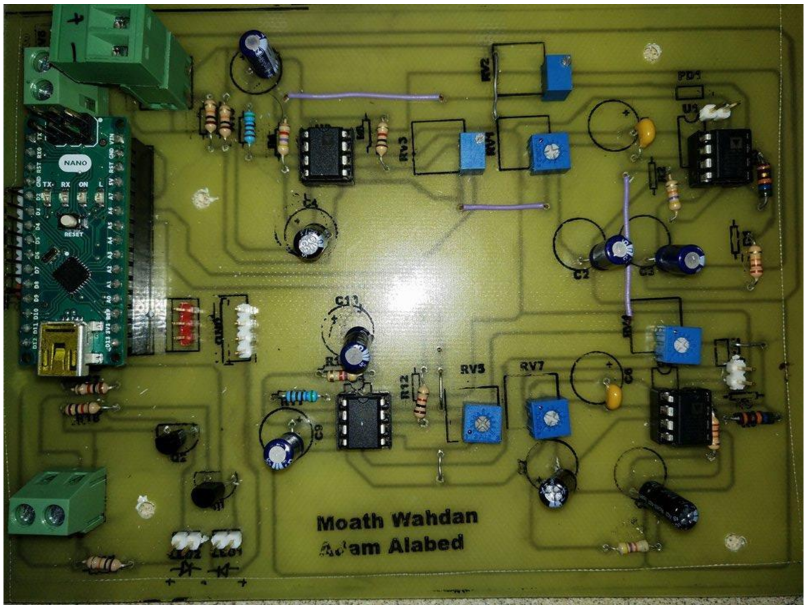


Figure 5. 2: Printed circuit board for the diagnostic system

5.1.3 Equation forming and results

Table 5. 1 : the table shows the output voltage difference from our device and the bilirubin concentration taking from dragger device (JM-105).

Baby number	voltage Difference output (V)	Bilirubin concentration (mg/dL)
1	0.01	12.7
2	0.02	12.1
3	0.03	11.2
4	0.04	10.2
5	0.07	9.4
6	0.1	8.8
7	0.11	8.6
8	0.17	6
9	0.15	5.4
10	0.19	5.2
11	0.2	4.5
12	0.21	3.8
13	0.25	2.7
14	0.28	2.4
15	0.3	2.2
16	0.35	2
17	0.37	1.8
18	0.47	1.4

In order to get bilirubin concentration from the output voltage difference taken from our device curve fitting method used as shown in figure (5.3).

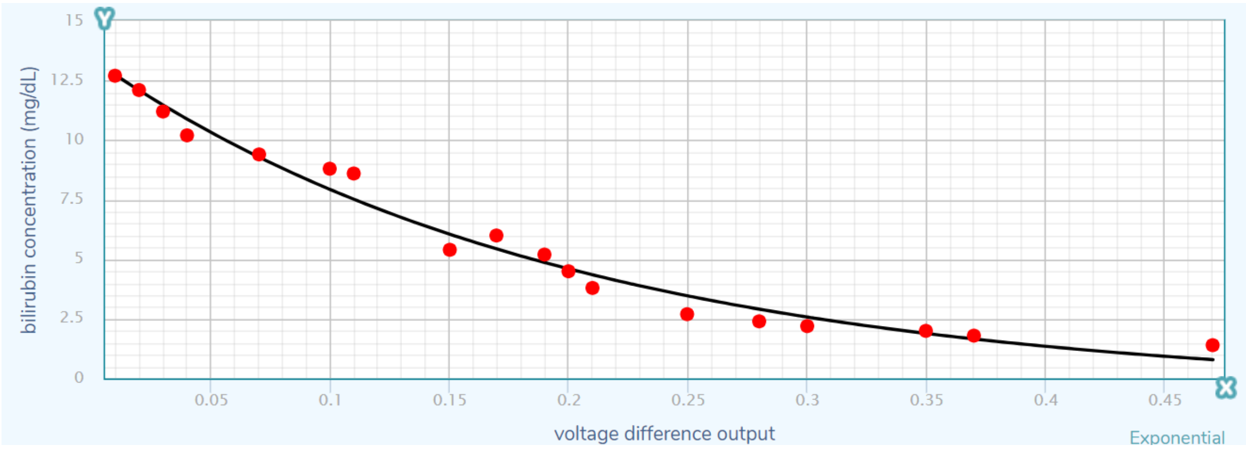


Figure 5.3 : the relationship between output voltage difference and bilirubin concentration.[19]

By using special program for curve fitting[1] , the result equation for the system was

$$Y = 13.48301 - \left(\frac{71.75146}{5.298067}\right) * (1 - e^{-5.298067\,X})$$

where :

Y:bilirubin concentration (mg/dL)

X: difference output voltage (V)

This equation is programmed inside the arduino code , so that the device converts the output voltage difference between the two detectors into a bilirubin concentration .

5.2 Phototherapy System

The phototherapy system main functionality is to break down bilirubin in the baby’s body using high intensity 455nm light . And this project was designed to be home used .

5.2.1 system connections and internal components

The internal construction and connections of the box represents the control and operating part of the phototherapy system as shown in figure (5.4)

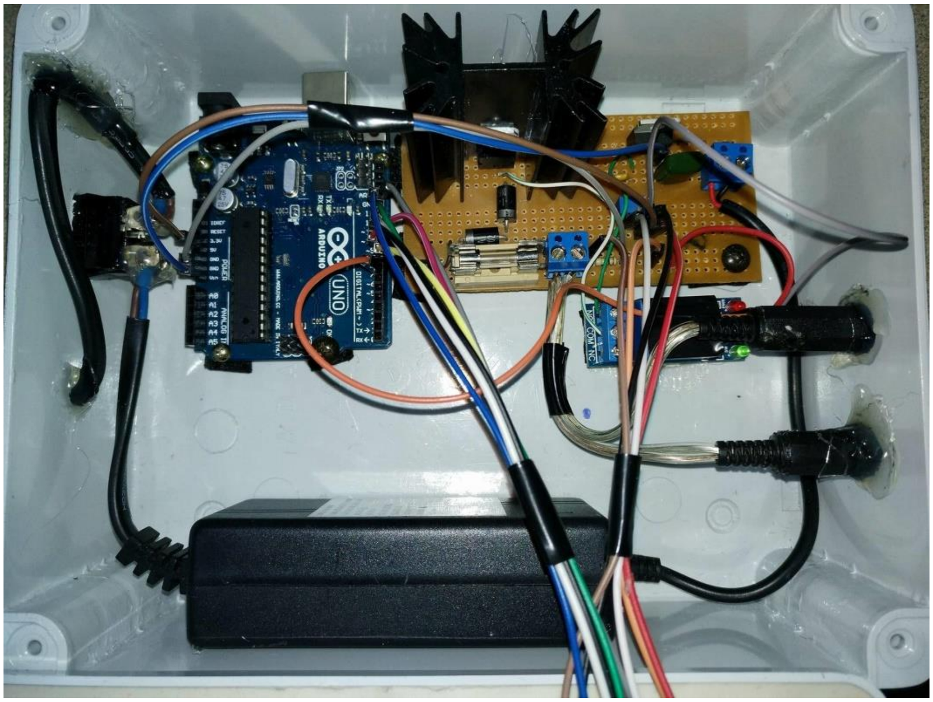


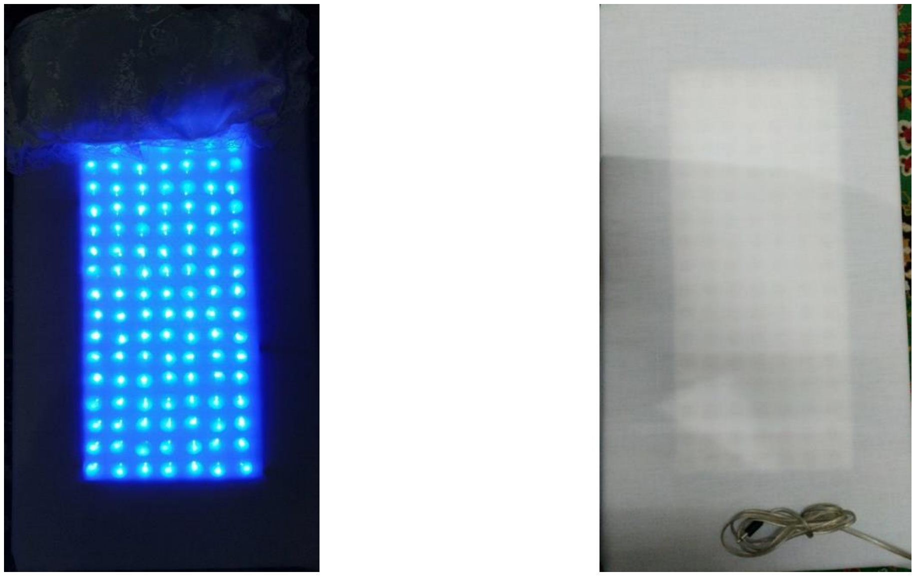
Figure 5. 4 : The internal construction and components of the phototherapy system

5.2.2 Final Form of The Device

After making several designs and layouts , the final design was as shown in figure (5.5) , which shown the user interface while operating the device ..

Figure 5. 5: The interface of the phototherapy system

The mattress chosen for the project was a medical mattress made of compressed sponge , so that when the baby is sleeping on it , it will not compress , and the baby will not have any contact with the LEDs , figure (5.6) shows the mattress last form while operating and when its off .



(a) (b)

Figure 5. 6: (a) The mattress while operating
(b) The mattress while off

The blanket is made of a regular baby blanket that covers the whole baby's body , and LEDs are placed inside it in such a way that the light covers the baby's chest and belly , as shown in figure (5.7).

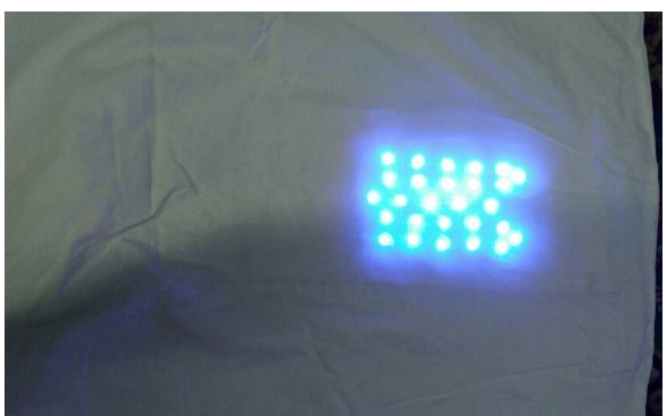


Figure 5. 7 : The blanket while operating .

5.2.3 Results and Readings

In the phototherapy system , the most important parameters are the wavelength and the intensity of light .

After operating and testing the phototherapy system using the Fluoro-lite meter device , which is used for measuring the irradiance for the phototherapy systems , the results was as following :

The irradiance in the normal day light = 0.3 $\mu W/cm^2.Nm$

The irradiance inside the system (between the mattress and blanket) = 12.2 $\mu W/cm^2.Nm$

The irradiance under the phototherapy devices used in hospital = (5 – 17) $\mu W/cm^2.Nm$

The irradiance test gave relatively high and very good results for the phototherapy system .

Chapter Six

Conclusion and recommendations

6.1 Conclusion

6.2 Recommendations and Future Work

6.1 Conclusion

From the results shown in chapter 5 , and after applying the diagnostic device for measuring bilirubin concentration the results were relatively accurate compared with the optical diagnostic device used in the hospital (dragger jm-103) .

The phototherapy system , was fully operated , flawlessly , and preforming its job as desired . By the measurements taken by the Fluoro-Lite Meter device its noticeable that the system has a high efficiency and very good irradiance .

6.2 Recommendations and Future work

In order to proceed with this project or develop it , we recommend with some points :

- In the phototherapy system , high frequency ICs are better to be used , especially when using photodiodes .
- When designing the PCB , print on two layers board to make the design more compact .
- Use a larger LCD screen and show the state of the baby level after showng the bilirubin concentration .
- Using transmittance for measuring in thin areas of the body (like hand palm or fingers) might be easier to handle or more accurate .
- When taking samples , large count samples should be taken .
- When taking samples , age , skin color , race and gender should be taken in consideration.

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