DESIGN OF A MICROCONTROLLER BASED DEVICE TO MEASURE THE HEART RATE FROM THE FINGER

GRADUATION PROJECT SUBMITTED TO THE ENGINEERING FACULTY

OF

NEAR EAST UNIVERSITY

By

MORENIKE IHEME

In Partial Fulfillment of the Requirements for

The Degree of Bachelor of Science

In

Biomedical Engineering

Supervisor: Prof Dr. Dogan Ibrahim

NICOSIA-2013

ACKNOWLEDGEMENT

I would like to recognize and appreciate the very special people who have had a hand in my successes and growth in Biomedical Engineering Department, Near East University.

First and foremost, without my parents, I wouldn't have been in Cyprus in the first place. Thank you so much for your support, encouragement and love. I really couldn't have done this without you, Andee and Moji Iheme.

Prof. Dr. Dogan Ibrahim, thank you so much for your patience and understanding throughout my stay in NEU and during my graduation project preparation. I had a million questions, and for each, you had an answer. Thank you so much.

Assist. Prof. Dr. Terin Adali, you were the best course advisor I could have asked for. You gave me good advice throughout my stay in NEU. Your excellent teaching skills have impacted me mightily. Thank you.

Assist. Prof. Dr. Umut Fahrioglu, you were my best teacher, it just seemed appropriate to thank you. All your classes were wonderful.

To all my teachers, friends and classmates, thank you so much for making my stay in NEU worth every second. God bless.

ABSTRACT

The measurement of heart rate is used by medical professionals to assist in the diagnosis and tracking of medical conditions. It is also used by individuals, such as athletes, who are interested in monitoring their heart rate to gain maximum efficiency from their training. Hence, the importance of heart rate and its measurement cannot be over emphasized.

The aim of this project is to design a low-cost microcontroller based device to measure heart rate. The use of this device is very simple. Turn the power on, and you will see all zeros on display for few seconds. Wait till the display goes off. Now place your forefinger tip on the sensor assembly, and press the start button. Just relaxed and don’t move your finger. You will see the LED blinking with heart beats, and after 15 sec, the result will be displayed.

ÖZET

Kalp hızı ölçümü tıbbi durumlar tanı ve izleme yardımcı olmak için tıp uzmanları tarafından kullanılır. Aynı zamanda onların eğitimden maksimum verim elde etmek için kendi kalp hızı izleme ilgilenen sporcular, bireyler, tarafından kullanılır. Bu nedenle, kalp hızı ve ölçümü önemi üzerinde vurguladı olamaz.

Bu projenin amacı, kalp hızı ölçmek için düşük maliyetli bir mikroişlemci tabanlı cihaz tasarlamaktır. Bu cihazın kullanımı çok basittir. Gücü açın ve birkaç saniye ekranda tüm sıfır göreceksiniz.Ekran kapanır kadar bekleyin. Şimdi sensör montaj işaret parmağı ucu yerleştirin ve start düğmesine basın. Sadece rahat ve parmağınızı hareket etmiyor. Eğer kalp atım ile LED yanıp göreceksiniz, ve 15 saniye sonra, sonuç görüntülenir.

Contents

ACKNOWLEDGEMENT 1
ABSTRACT 2
ÖZET 2
LIST OF FIGURES 5
CHAPTER 1 6
WHAT IS HEART RATE? 6
1.1 INTRODUCTION 6
1.2 MEASUREMENT OF HEART RATE 7
1.3 Why do you need to monitor your heart rate? 8
Recovery Heart Rate 10
1.4 ABNORMALITIES OF HEART RATE 10
1.4.1 Tachycardia 10
1.4.2 Bradycardia 11
1.4.3 Arrhythmia 11
CHAPTER 2 12
THE FINGER(S) 12
2.1 INTRODUCTION 12
2.2 ANATOMY OF THE HUMAN FINGERS 13
2.2.1 Bones 13
FIGURE 2.1 HUMAN FINGER BONES 14
2.3 MUSCLES 15
FIGURE 2.4 HUMAN ARM MUSCLES 17
2.4 NERVE SUPPLY AND BLOOD FLOW TO THE WIST AND HAND 18
2.4.1 The nerves 18
2.5 The arteries and veins 19
FIGURE 2.6 21
CHAPTER 3 22
DESIGN OF A DEVICE TO MEASURE HEART RATE FROM THE FINGER 22
3.1 INTRODUCTION 22

FIGURE 3.1 THE DESIGNED SYSTEM 23
FIGURE 3.2 THE DESIGNED SYSTEM ON THE PCB 24
3.2 Theory 24
3.3 SENSOR ASSEMBLY 24
FIGURE 3.3 THE PHOTODIODE ASSEMBLY 25
3.4 Circuit Diagram 25
FIGURE 3.4 CIRCUIT DIAGRAM OF THE PROJECT 26
3.5 MICROCONTROLLER AND DISPLAY CIRCUIT 26
FIGURE 3.5 THE DISPLAY CIRCUIT 27
CHAPTER 4 27
THE SOFTWARE 27
4.1 INTRODUCTION 27
CHAPTER 5 31
THE OUTPUT 31
5.1 INTRODUCTION 31
FIGURE 5.1 TESTING THE SYSTEM 32
5.2 IMPORTANT NOTES 32
FIGURE 5.2 PLACING THE FINGER ON THE SENSOR 33
CHAPTER 6 35
BUILDING THE DEVICE 35
6.1 INTRODUCTION 35
6.2 The Hardware 35
FIGURE 6.2 FILTERING CHARACTERISTICS OF THE CIRCUIT 36
6.3 The Ready for PIC board 37
FIGURE 6.3 THE READY FOR PIC DEVELOPMENT BOARD 37
6.4 The complete circuit 38
6.5 The Software 38
6.6 The program 39
CHAPTER 7 41
CONCLUSIONS 41
REFERENCES 42
APPENDIX A 43

OP295 DATA SHEET..43
END 107

LIST OF FIGURES

FIGURE 1.1 Human Fingers .... **Error! Bookmark not defined.**
FIGURE 2.1 HUMAN FINGER BONES .... **Error! Bookmark not defined.**
FIGURE 2.2 INDEX FINGER AND FINGER BONES .... **Error! Bookmark not defined.**
FIGURE 2.4 HUMAN ARM MUSCLES .... **Error! Bookmark not defined.**
FIGURE 2.6 .... **Error! Bookmark not defined.**
FIGURE 2.7 VEINS OF THE ARM.. **Error! Bookmark not defined.**
FIGURE 3.1 THE DESIGNED SYSTEM... **Error! Bookmark not defined.**
FIGURE 3.2 THE DESIGNED SYSTEM ON THE PCB .... **Error! Bookmark not defined.**
FIGURE 3.3 THE PHOTODIODE ASSEMBLY .... **Error! Bookmark not defined.**
FIGURE 3.4 CIRCUIT DIAGRAM OF THE PROJECT....................................... **Error! Bookmark not defined.**
FIGURE 3.5 THE DISPLAY CIRCUIT .... **Error! Bookmark not defined.**
FIGURE 5.1 TESTING THE SYSTEM.. **Error! Bookmark not defined.**
FIGURE 5.2 PLACING THE FINGER ON THE SENSOR.................................... **Error! Bookmark not defined.**
FIGURE 6.2 FILTERING CHARACTERISTICS OF THE CIRCUIT .... **Error! Bookmark not defined.**
FIGURE 6.3 THE READY FOR PIC DEVELOPMENT BOARD .... **Error! Bookmark not defined.**

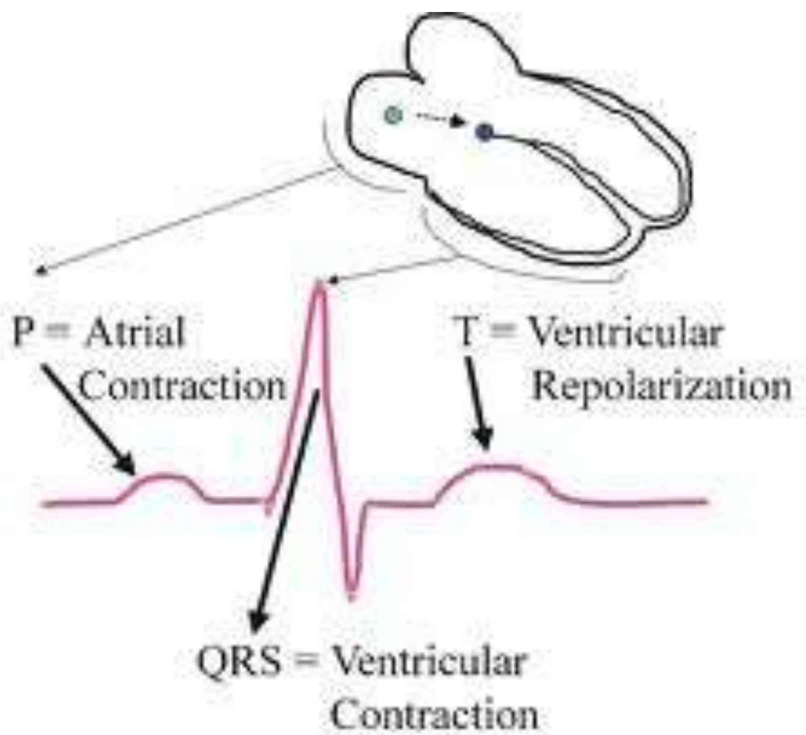
CHAPTER 1

WHAT IS HEART RATE?

1.1 INTRODUCTION

Heart rate is the number of heartbeats per unit of time, typically expressed as beats per minute (bpm). Heart rate can vary as the body's need to absorb oxygen and excrete carbon dioxide changes, such as during physical exercise or sleep.

The measurement of heart rate is used by medical professionals to assist in the diagnosis and tracking of medical conditions. It is also used by individuals, such as athletes, who are interested in monitoring their heart rate to gain maximum efficiency from their training. The R wave to R wave interval (RR interval) is the inverse of the heart rate.



In layman’s terms, heart rate is the number of heartbeats per unit of time, usually expressed as beats per minute.

1.2 MEASUREMENT OF HEART RATE

Heart rate is measured by finding the pulse of the body. This pulse rate can be measured at any point on the body where the artery's pulsation is transmitted to the surface by pressuring it with the index and middle fingers; often it is compressed against an underlying structure like bone. The thumb should not be used for measuring another person's heart rate, as its strong pulse may interfere with correct perception of the target pulse.

Possible points for measuring the heart rate are:

- The ventral aspect of the wrist on the side of the thumb (radial artery).
- The ulnar artery.
- The neck (carotid artery).
- The inside of the elbow, or under the biceps muscle (brachial artery).
- The groin (femoral artery).
- Behind the medial malleolus on the feet (posterior tibial artery).
- **The finger**
- Middle of dorsum of the foot (dorsalis pedis).
- Behind the knee (popliteal artery).
- Over the abdomen (abdominal aorta).
- The chest (apex of the heart), which can be felt with one's hand or fingers. However, it is possible to auscultate the heart using a stethoscope.
- The temple (superficial temporal artery).

- The lateral edge of the mandible (facial artery).
- The side of the head near the ear (basilar artery)

1.3 Why do you need to monitor your heart rate?

Measuring heart rate gives very important information about your health. Any change from normal heart rate can indicate a medical condition. It can help determine if the patient's heart is still pumping, particularly in emergency situations.

The pulse measurement has another use as well. During exercise or immediately after exercise, the heart rate can give information about your cardiovascular fitness level and health. To receive the complete benefits of a workout, you need to stay in your working heart rate range for at least 20 to 30 minutes continuously. Therefore, proper pacing during exercise is important.

There are three different heart rates which you should keep in mind:

RESTING HEART RATE

This is a person's heart rate at rest. The best time to find out your resting heart rate is after sitting quietly for a while or before you get out of bed after a good night sleep. The normal resting heart rate is about 60 to 80 beats a minute when we are at rest. Resting heart rate usually rises with age, but generally lowers in physically fit people. Moreover, resting heart rate is used to determine one's training target heart rate and to find out if you are over-trained.

WORKING HEART RATE

Working heart rates let you measure your initial fitness level and monitor your progress in a fitness program. This approach requires measuring your pulse periodically as you work out and staying within 50 to 85 percent of your maximum heart rate. The table below shows estimated target heart rates for different ages.

Working Heart Rate Range

Chart Beats Per Minute (BPM)

Resting Heart Rate	Age: 30 & Under	31-40	41-45	46-50	51-55	56-60	61-65	Over 65
50-51	140-190	130-190	130-180	120-170	120-170	120-160	110-150	110-150
52-53	140-190	130-190	130-180	120-170	120-170	120-160	110-150	110-150
54-56	140-190	130-190	130-180	120-170	120-170	120-160	110-150	110-150
57-58	140-190	130-190	130-180	130-170	120-170	120-160	110-150	110-150
59-61	140-190	140-190	130-180	130-170	120-170	120-160	110-150	110-150
62-63	140-190	140-190	130-180	130-170	120-170	120-160	120-150	110-150
64-66	140-190	140-190	130-180	130-170	130-170	120-160	120-150	110-150
67-68	140-190	140-190	140-180	130-170	130-170	120-160	120-150	110-150
69-71	150-190	140-190	140-180	130-170	130-170	120-160	120-150	120-150
72-73	150-190	140-190	140-180	130-170	130-170	130-160	120-150	120-150
74-76	150-190	140-190	140-180	130-170	130-170	130-160	120-150	120-150
77-78	150-190	140-190	140-180	130-170	130-170	130-160	120-150	120-150
79-81	150-190	140-190	140-180	130-170	130-170	130-160	120-150	120-150
82-83	150-190	140-190	140-180	140-170	130-170	130-160	120-150	120-150
84-86	150-	150-	140-	140-	130-	130-	120-	120-

	190	190	180	170	170	160	150	150
87-88	150-190	150-190	140-180	140-170	130-170	130-160	130-150	120-150

Recovery Heart Rate

One way to determine if you are gaining the benefits from exercise is to calculate your Recovery Heart Rate, which is a measure of how quickly you return to your resting heart rate after a workout. Nevertheless, the heart rate is a convenient and reliable indicator of the intensity of your exercise. It is good to monitor it so that you can adjust depending on your fitness level and the goals you want to achieve by exercising. Thus, heart rate monitoring brings benefits to all levels of users.

1.4 ABNORMALITIES OF HEART RATE

1.4.1 Tachycardia

Tachycardia is a resting heart rate more than 100 beats per minute. This number can vary as smaller people and children have faster heart rates than average adults.

Physiological conditions when tachycardia occurs are

1. Exercise
2. Pregnancy
3. Emotional conditions such as anxiety or stress.

Pathological conditions when tachycardia occurs are:

1. Fever
2. Anemia
3. Hypoxia
4. Hyperthyroidism
5. Hyper secretion of catecholamine

6. Cardiomyopathy
7. Valvular heart diseases
8. Acute Radiation Syndrome

1.4.2 Bradycardia

Bradycardia is defined as a heart rate less than 60 beats per minute although it is seldom symptomatic until below 50 bpm when a human is at total rest. This number can vary as children and small adults tend to have faster heart rates than average adults. Bradycardia may be associated with medical conditions such as hypothyroidism.

Trained athletes tend to have slow resting heart rates, and resting bradycardia in athletes should not be considered abnormal if the individual has no symptoms associated with it. For example Miguel Indurain, a Spanish cyclist and five time Tour de France winner, had a resting heart rate of 28 beats per minute, one of the lowest ever recorded in a healthy human.

1.4.3 Arrhythmia

Arrhythmias are abnormalities of the heart rate and rhythm (sometimes felt as palpitations). They can be divided into two broad categories: fast and slow heart rates. Some cause few or minimal symptoms. Others produce more serious symptoms of lightheadedness, dizziness and fainting.

For the purpose of this project, I am going to focus on **measurement of heart rate from the finger**. Before I begin, I would like to provide information on the human finger, so that this topic will be very well understood and appreciated. Figure 1.1 shows the human fingers:

FIGURE 1.1 Human Fingers

CHAPTER 2

THE FINGER(S)

2.1 INTRODUCTION

A finger is a limb of the human body and a type of digit, an organ of manipulation and sensation found in the hands of humans and other primates. Normally humans have five digits, the bones of whom are termed phalanges, on each hand (exceptions are polydactyly, oligodactyly and digit loss).

- The first digit is the Thumb
- followed by index finger
- middle finger
- ring finger
- And little finger or pinky.

Some other languages use the same generic term for all five digits of a hand.

2.2 ANATOMY OF THE HUMAN FINGERS

2.2.1 Bones

The thumb (connected to the trapezium) is located on one of the sides, parallel to the arm.

The palm has five bones known as metacarpal bones, one to each of the 5 digits. Human hands contain fourteen digital bones, also called phalanges, or phalanx bones: two in the thumb (the thumb has no middle phalanx) and three in each of the four fingers. These are the distal phalanx, carrying the nail, the middle phalanx, and the proximal phalanx.

Sesamoid bones are small ossified nodes embedded in the tendons to provide extra leverage and reduce pressure on the underlying tissue. Many exist around the palm at the bases of the digits; the exact number varies between different people.

The articulations are: interphalangeal articulations between phalangeal bones, and metacarpophalangeal joints connecting the phalanges to the metacarpal bones. They're all synovial joints with synovial membranes and fibrous joint capsules.

- Metacarpophalangeal joints: Connecting the proximal phalanges to the metacarpals are condyloid joints with strong palmar and collateral ligaments that allow for movement in different directions (flexion, extension, abduction, adduction, circumduction). You may recognize them as your knuckles.

- Interphalangeal joints: These hinge joints allow flexion and extension. They join the heads of the phalanges with the bases of the next distal phalanges. Each finger (digits two through five) has one proximal interphalangeal joint and one distal interphalangeal joint. The thumb has only one interphalangeal joint.

The pulp of a finger is the fleshy mass on the palmar aspect of the extremity of the finger.

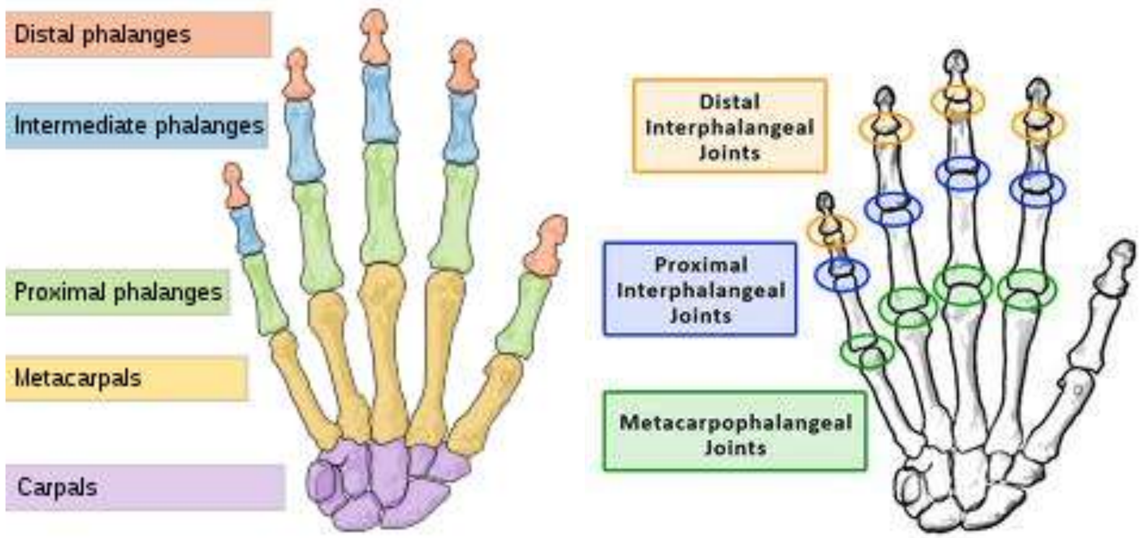


FIGURE 2.1 **HUMAN FINGER BONES**

FIGURE 2.2 INDEX FINGER AND FINGER BONES

2.3 MUSCLES

Each finger may flex and extend, abduct and adduct, and so also circumduct. Flexion is by far the strongest movement. In humans, there are two large muscles that produce flexion of each finger, and additional muscles that augment the movement. Each finger may move independently of the others, though the muscle bulks that move each finger may be partly blended, and the tendons may be attached to each other by a net of fibrous tissue, preventing completely free movement.

Fingers do not contain muscles other than arrector pili muscles. The muscles that move the finger joints are in the palm and forearm. The long tendons that deliver motion from the forearm muscles may be observed to move under the skin at the wrist and on the back of the hand.

Muscles of the fingers can be subdivided into **extrinsic** and **intrinsic** muscles. The extrinsic muscles are the long flexors and extensors. They are called extrinsic because the muscle belly is located on the forearm.

The fingers have two long flexors, located on the underside of the forearm. They insert by tendons to the phalanges of the fingers. The deep flexor attaches to the distal phalanx, and the superficial flexor attaches to the middle phalanx. The flexors allow for the actual bending of the fingers. The thumb has one long flexor and a short flexor in the thenar muscle group. The human thumb also has other muscles in the thenar group (opponens and abductor brevis muscle), moving the thumb in opposition, making grasping possible.

The extensors are located on the back of the forearm and are connected in a more complex way than the flexors to the dorsum of the fingers. The tendons unite with the interosseous and lumbrical muscles to form the extensorhood mechanism. The primary function of the extensors is to straighten out the digits. The thumb has two extensors in the forearm; the tendons of these form the anatomical snuff box. Also, the index finger and the little finger have an extra extensor, used for instance for pointing. The extensors are situated within 6 separate compartments. The 1st compartment contains abductor pollicis longus and extensor pollicis brevis. The 2nd compartment contains extensors carpi radialis longus and brevis. The 3rd compartment contains extensor pollicis longus. The extensor digitorum indicis and extensor digititorum communis are within the 4th compartment. Extensor digiti minimi is in the fifth, and extensor carpi ulnaris is in the 6th.

The intrinsic muscle groups are the thenar and hypothenar muscles (thenar referring to the thumb, hypothenar to the small finger), the dorsal and palmar interossei muscles (between the metacarpal bones) and the lumbrical muscles. The lumbricals arise from the deep flexor (and are special because they have no bony origin) and insert on the dorsal extensor hood mechanism.

FIGURE 2.3 HAND MUSCLES

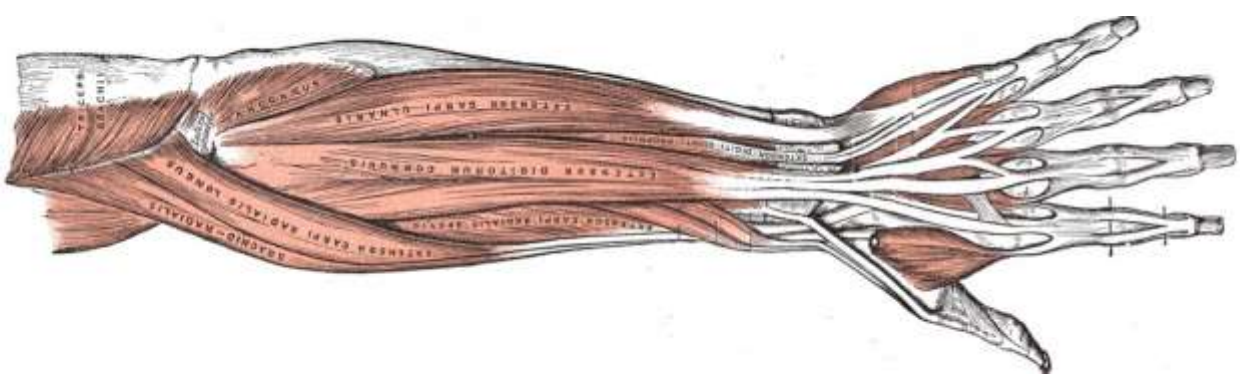


FIGURE 2.4 **HUMAN ARM MUSCLES**

2.4 NERVE SUPPLY AND BLOOD FLOW TO THE WIST AND HAND

This aspect of my background report on my project is very important, as it brings us closer to the measurement of blood flow / heart rate from the finger.

Busy muscles need plenty of nerve supply and blood flow. Three main nerves (plus all their branches) work the wrist and hand, and many arteries and veins bring blood into and out of the hand.

2.4.1 The nerves

The main nerves you need to know for the wrist and hand come from the median, ulnar, and radial nerves. These nerves supply the skin, muscles, joints, and other tissues. The nerves allow you to feel what your hands and fingers are touching and help you move those muscles around.

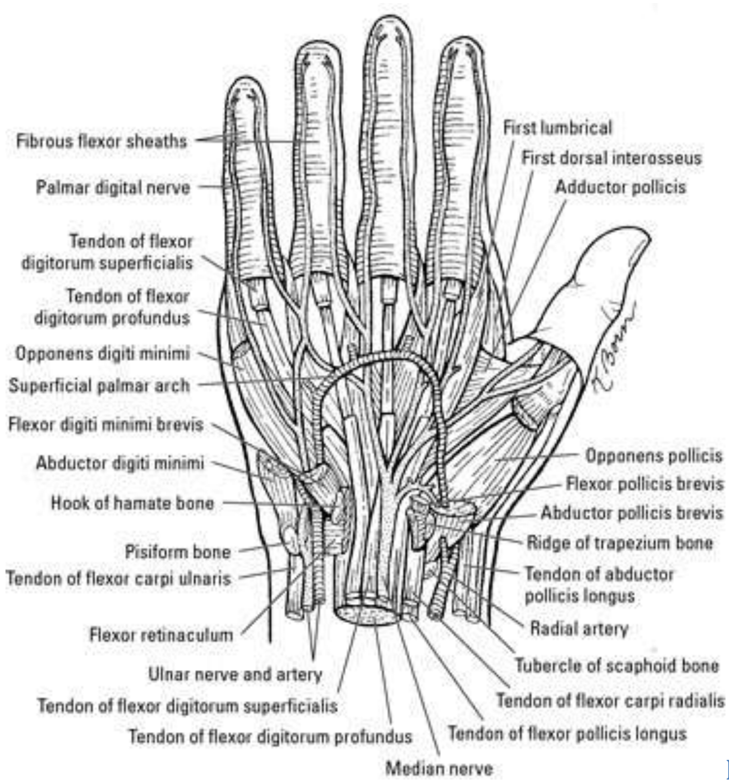


FIGURE 2.5 NERVES OF THE PALM

- **Median nerve:** The median nerve enters the hand through the carpal tunnel, which is a passageway between the tubercles of the scaphoid and trapezium bones laterally and by the pisiform and the hook of the hamate on the medial side. It gives nerve supply to the thenar muscles and the first two lumbricals, plus it sends sensory fibers to the skin on the lateral part of the palm and to the sides and distal portions of the first three digits.

  The palmar cutaneous branch of the median nerve branches off before the carpal tunnel. It innervates the middle of the palm.

- **Ulnar nerve:** The ulnar nerve comes from under the tendon of the flexor carpi ulnaris and runs through the ulnar tunnel (or tunnel of Guyon), which is between the pisiform and the hook of the hamate. The ulnar nerve and its dorsal cutaneous, palmar cutaneous, and superficial branches innervate the medial portion of the wrist and hand and the medial one and a half digits.

- **Radial nerve:** The radial nerve has two branches in the forearm: The deep branch runs through the posterior part of the forearm, supplying motor innervation to the extensor muscles. The superficial branch is a cutaneous nerve that runs under the brachioradialis muscle and passes through the anatomical snuff box, which is a visible depression formed near the base of the thumb by the tendons of the extensor pollicis longus and extensor pollicis brevis muscles. It doesn't innervate any intrinsic hand muscles; instead, it innervates the skin and fascia of the lateral portion of the back of the hand and lateral three and half digits.

2.5 The arteries and veins

The ulnar and radial arteries carry blood down through the forearm into the wrist, where they anastomose (join together) to form arches. These arches, along with several branches, supply blood to the hand and digits.

Here are the arteries that enter the wrist:

- Anterior **interosseous artery:** This artery runs from the ulnar artery anterior to the interosseous membrane. It pierces the membrane distally to join the dorsal carpal arch.
- **Palmar carpal branch:** This branch runs from the ulnar artery over the anterior part of the wrist under the flexor digitorum profundus tendons.
- **Dorsal carpal branch:** This branch runs from the ulnar artery across the back of the wrist under the extensor tendons.
- **Palmar carpal branch:** This branch runs from the radial artery across the anterior wrist underneath the flexor tendons.
- **Dorsal carpal branch:** This branch runs from the radial artery across the wrist beneath the pollicis and extensor radialis tendons.
- These carpal branches of the ulnar arteries join together with the carpal branches of the radial arteries to form two arches in the wrist:
- **Palmar carpal arch:** The area where the palmar carpal branches of the radial and ulnar arteries meet
- **Dorsal carpal arch:** Formed by the anastomoses of the dorsal carpal branches of the radial and ulnar arteries

Next up are the arteries and branches that supply blood to the hands and fingers. They also come from the radial and ulnar arteries.

- **Superficial palmar arch:** This arch is formed by the ulnar artery anastomosing with a superficial branch of the radial artery. It runs in front of the flexor tendons near the middle of the metacarpal bones.
- **Deep palmar arch:** This arch is made by the radial artery and a deep branch of the ulnar artery. It runs along the bases of the metacarpals.
- **Common palmar digitals:** These branches leave the superficial palmar arch to run along the lumbricals to the webbing of the fingers.

- **Proper palmar digitals:** These branches start from the common palmar digitals and run along the sides of the fingers, but not the thumb.

- **Princeps pollicis:** This artery starts at the radial artery at the palm and descends to past the first metacarpal to the proximal phalanx of the thumb. There it splits into two branches that run along the sides of the thumb.

- **Radialis indicis:** This branch arises from the radial artery and runs along the lateral side of the index finger.

The superficial and deep palmar venous arches return blood to the heart and are located near the arterial arches. They drain into the deep veins of the forearm. Dorsal digital veins drain into dorsal metacarpal veins, which form the dorsal venous network. This blood drains into the cephalic and basilic veins.

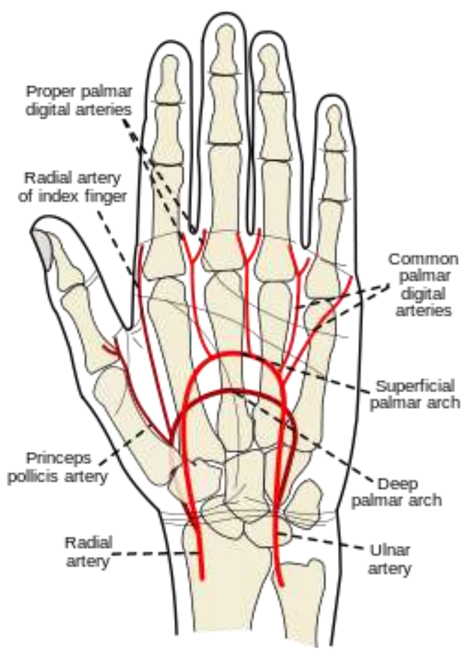
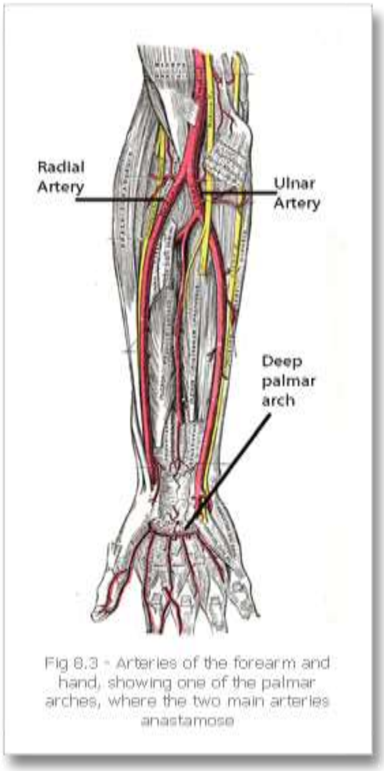


FIGURE 2.6 BONES OF THE HANDS AND ARM



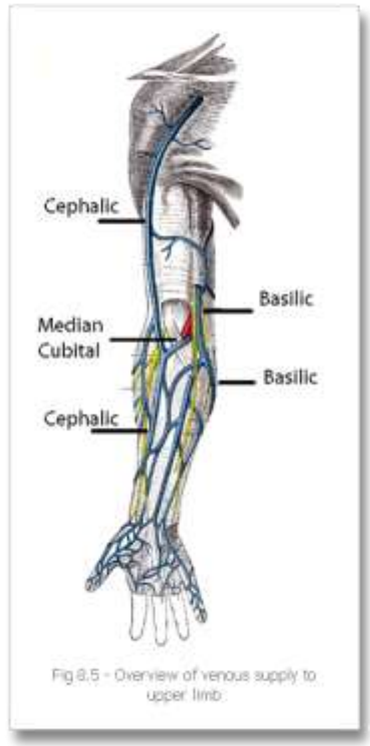


FIGURE 2.7 VEINS OF THE ARM

CHAPTER 3

DESIGN OF A DEVICE TO MEASURE HEART RATE FROM THE FINGER

3.1 INTRODUCTION

Figure 3.1 shows a picture of the designed system.

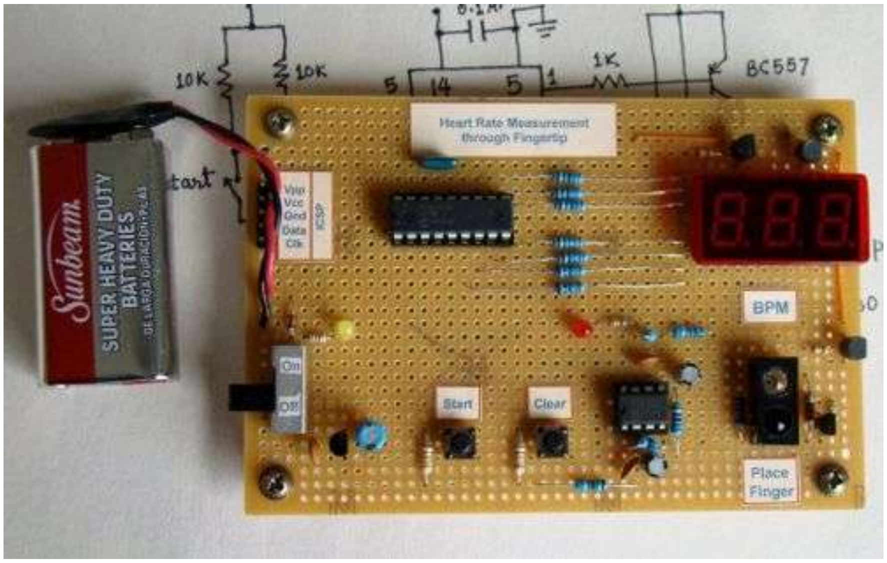


FIGURE 3.1 **THE DESIGNED SYSTEM**

I have hopefully established in your minds that the blood supply to the finger tips are very well supplied with blood from the circulation, and are hence very suitable for measurement of the heart rate. Change in the heart rate affect the blood flow to the finger tips and the pulse changes accordingly.

Heart rate measurement indicates the soundness of the human cardiovascular system. This project demonstrates a technique to measure the heart rate by sensing the change in blood volume in a finger artery while the heart is pumping the blood. It consists of an infrared LED that transmits an IR signal through the fingertip of the subject, a part of which is reflected by the blood cells. The reflected signal is detected by a photo diode sensor. The changing blood volume with heartbeat results in a train of pulses at the output of the photo diode, the magnitude of which is too small to be detected directly by a microcontroller. Therefore, a two-stage high gain, active low pass filter is designed using two Operational Amplifiers (OpAmps) to filter and amplify the signal to appropriate voltage level so that the pulses can be counted by a microcontroller. The heart rate is displayed on a 3 digit seven segment display. The microcontroller used in this project is PIC16F628A.

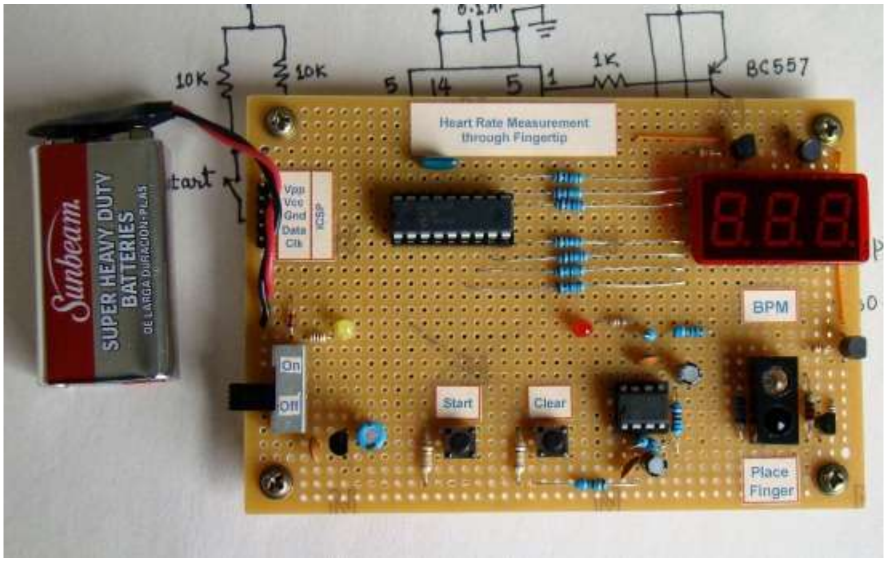


FIGURE 3.2 **THE DESIGNED SYSTEM ON THE PCB**

3.2 Theory

Heart rate is the number of heartbeats per unit of time and is usually expressed in beats per minute (bpm). In adults, a normal heart beats about 60 to 100 times a minute during resting condition. The resting heart rate is directly related to the health and fitness of a person and hence is important to know. You can measure heart rate at any spot on the body where you can feel a pulse with your fingers. The most common places are wrist and neck. You can count the number of pulses within a certain interval (say 15 sec), and easily determine the heart rate in bpm.

3.3 SENSOR ASSEMBLY

This project describes a microcontroller based heart rate measurement system that uses optical sensors to measure the alteration in blood volume at fingertip with each heartbeat. The sensor unit consists of an infrared light-emitting-diode (IR LED) and a photodiode, placed side by side as shown below. The IR diode transmits an infrared light into the fingertip (placed over the sensor unit), and the photodiode senses the portion of the light that is reflected back. The intensity of reflected light depends upon the blood volume inside the fingertip. So, each heart beat slightly alters the amount of reflected infrared light that can be detected by the photodiode. With a proper signal conditioning, this little change in the amplitude of the reflected light can be converted into a pulse. The pulses can be later counted by the microcontroller to determine the heart rate.

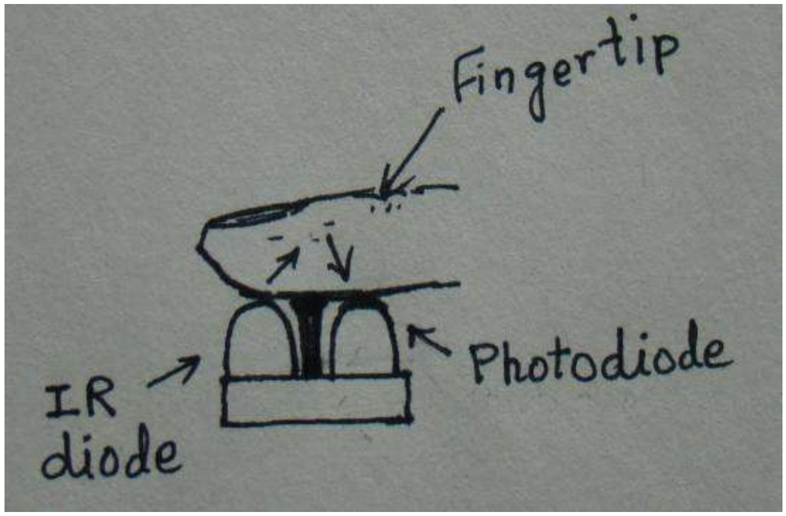


FIGURE 3.3 **THE PHOTODIODE ASSEMBLY**

3.4 Circuit Diagram

The signal conditioning circuit consists of two identical active low pass filters with a cut-off frequency of about 2.5 Hz. This means the maximum measurable heart rate is about 150 bpm. The operational amplifier IC used in this circuit is MCP602, a dual OpAmp chip from Microchip. It operates at a single power supply and provides rail-to-rail output swing. The filtering is necessary to block any higher frequency noises present in the signal. The gain of each filter stage is set to 101, giving the total amplification of about 10000. A 1 uF capacitor at the input of each stage is required to block the dc component in the signal. The equations for calculating gain and cut-off frequency of the active low pass filter are shown in the circuit diagram. The two stage amplifier/filter provides sufficient gain to boost the weak signal coming from the photo sensor unit and convert it into a pulse. An LED connected at the output blinks every time a heartbeat is detected. The output from the signal conditioner goes to the T0CKI input of PIC16F628A.

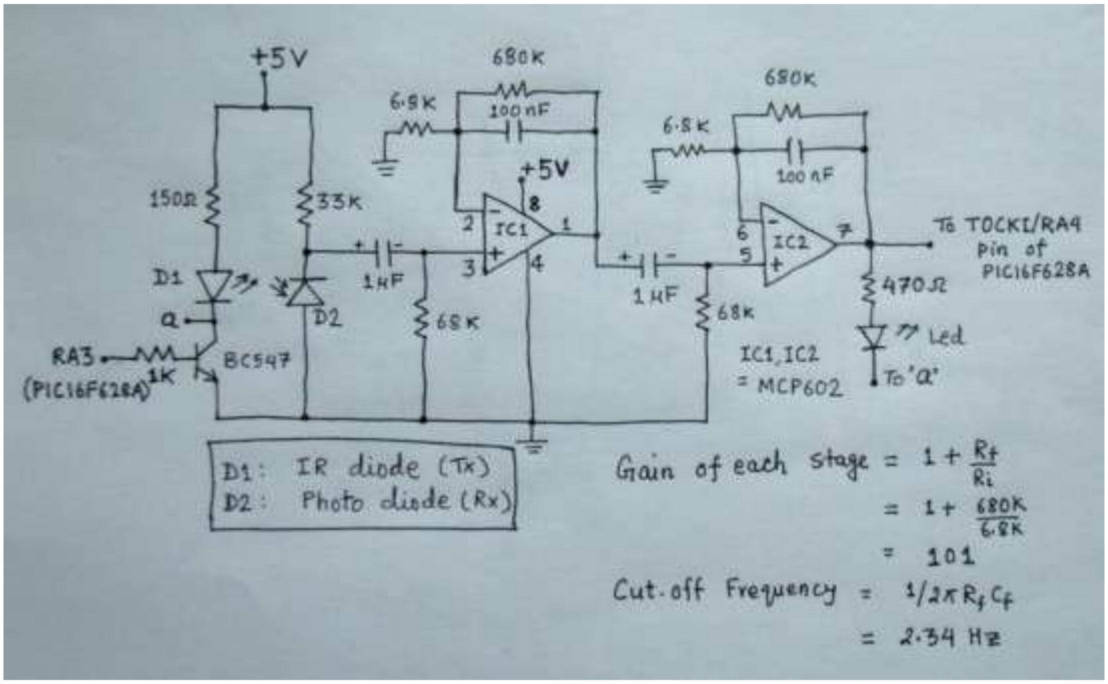


FIGURE 3.4 **CIRCUIT DIAGRAM OF THE PROJECT**

3.5 MICROCONTROLLER AND DISPLAY CIRCUIT

The control and display part of the circuit is shown below. The display unit comprises of a 3-digit, common anode, seven segment module that is driven using multiplexing technique. The segments a-g are driven through PORTB pins RB0-RB6, respectively. The unit's, ten's and hundred's digits are multiplexed with RA2, RA1, and RA0 port pins. A tact switch input is connected to RB7 pin. This is to start the heart rate measurement. Once the start button is pressed, the microcontroller activates the IR transmission in the sensor unit for 15 sec. During this interval, the number of pulses arriving at the T0CKI input is counted. The actual heart rate would be 4 times the count value, and the resolution of measurement would be 4. You can see the IR transmission is controlled through RA3 pin of PIC16F628A. The microcontroller runs at 4.0 MHz using an external crystal. A regulated +5V power supply is derived from an external 9 V battery using an LM7805 regulator IC.

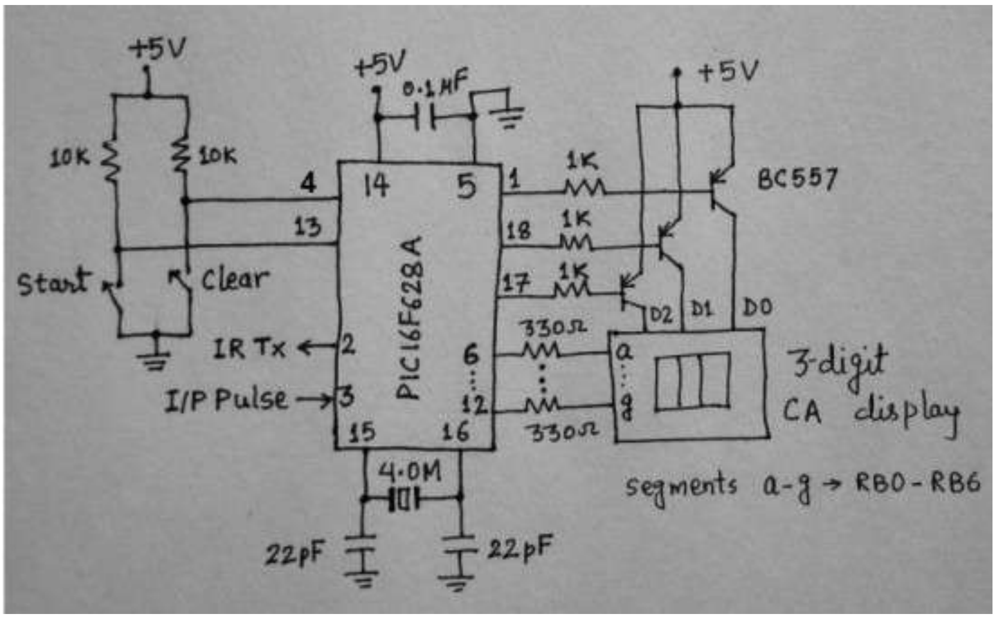


FIGURE 3.5 **THE DISPLAY CIRCUIT**

CHAPTER 4

THE SOFTWARE

4.1 INTRODUCTION

The firmware does all the control and computation operation. In order to save the power, the sensor module is not activated continuously. Instead, it is turned on for 15 sec only once the start button is pressed. The pulses arriving at T0CKI are counted through Timer0 module operated in counter mode without prescaler. The complete program written for MikroC compiler is provided below. The following code is for a design using a 3-digit 7-segment LED display.

```
/*
  Project: Measuring heart rate through fingertip
  PIC16F628A at 4.0 MHz external clock, MCLR enabled
*/

sbit IR_Tx at RA3_bit;
sbit DD0_Set at RA2_bit;
sbit DD1_Set at RA1_bit;
sbit DD2_Set at RA0_bit;
sbit start at RB7_bit;
unsigned short j, DD0, DD1, DD2, DD3;
unsigned short pulserate, pulsecount;
unsigned int i;
//-------------- Function to Return mask for common anode 7-seg. display
unsigned short mask(unsigned short num) {
 switch (num) {
 case 0 : return 0xC0;
 case 1 : return 0xF9;
 case 2 : return 0xA4;
 case 3 : return 0xB0;
 case 4 : return 0x99;
 case 5 : return 0x92;
 case 6 : return 0x82;
 case 7 : return 0xF8;
 case 8 : return 0x80;
 case 9 : return 0x90;
 } //case end
}
```

```
void delay_debounce(){
 Delay_ms(300);
}

void delay_refresh(){
 Delay_ms(5);
}

void countpulse(){
 IR_Tx = 1;
 delay_debounce();
 delay_debounce();
 TMR0=0;
 Delay_ms(15000);  // Delay 1 Sec
 IR_Tx = 0;
 pulsecount = TMR0;
 pulserate = pulsecount*4;
}

void display(){
  DD0 = pulserate%10;
  DD0 = mask(DD0);
  DD1 = (pulserate/10)%10;
  DD1 = mask(DD1);
  DD2 = pulserate/100;
  DD2 = mask(DD2);
  for (i = 0; i<=180*j; i++) {
    DD0_Set = 0;
    DD1_Set = 1;
```

```
    DD2_Set = 1;
    PORTB = DD0;
    delay_refresh();
    DD0_Set = 1;
    DD1_Set = 0;
    DD2_Set = 1;
    PORTB = DD1;
    delay_refresh();
    DD0_Set = 1;
    DD1_Set = 1;
    DD2_Set = 0;
    PORTB = DD2;
    delay_refresh();
    }
  DD2_Set = 1;
}

void main() {
 CMCON = 0x07;    // Disable Comparators
 TRISA = 0b00110000; // RA4/T0CKI input, RA5 is I/P only
 TRISB = 0b10000000; // RB7 input, rest output
 OPTION_REG = 0b00101000; // Prescaler (1:1), TOCS =1 for counter mode
 pulserate = 0;
 j = 1;
 display();
 do {
  if(!start){
   delay_debounce();
   countpulse();
```

```
  j= 3;
  display();
 }
} while(1);  // Infinite loop
}
```

CHAPTER 5

THE OUTPUT

5.1 INTRODUCTION

The use of this device is very simple. Turn the power on, and you will see all zeros on display for few seconds. Wait till the display goes off. Now place your forefinger tip on the sensor assembly, and press the start button. Just relaxed and don't move your finger. You will see the LED blinking with heart beats, and after 15 sec, the result will be displayed.

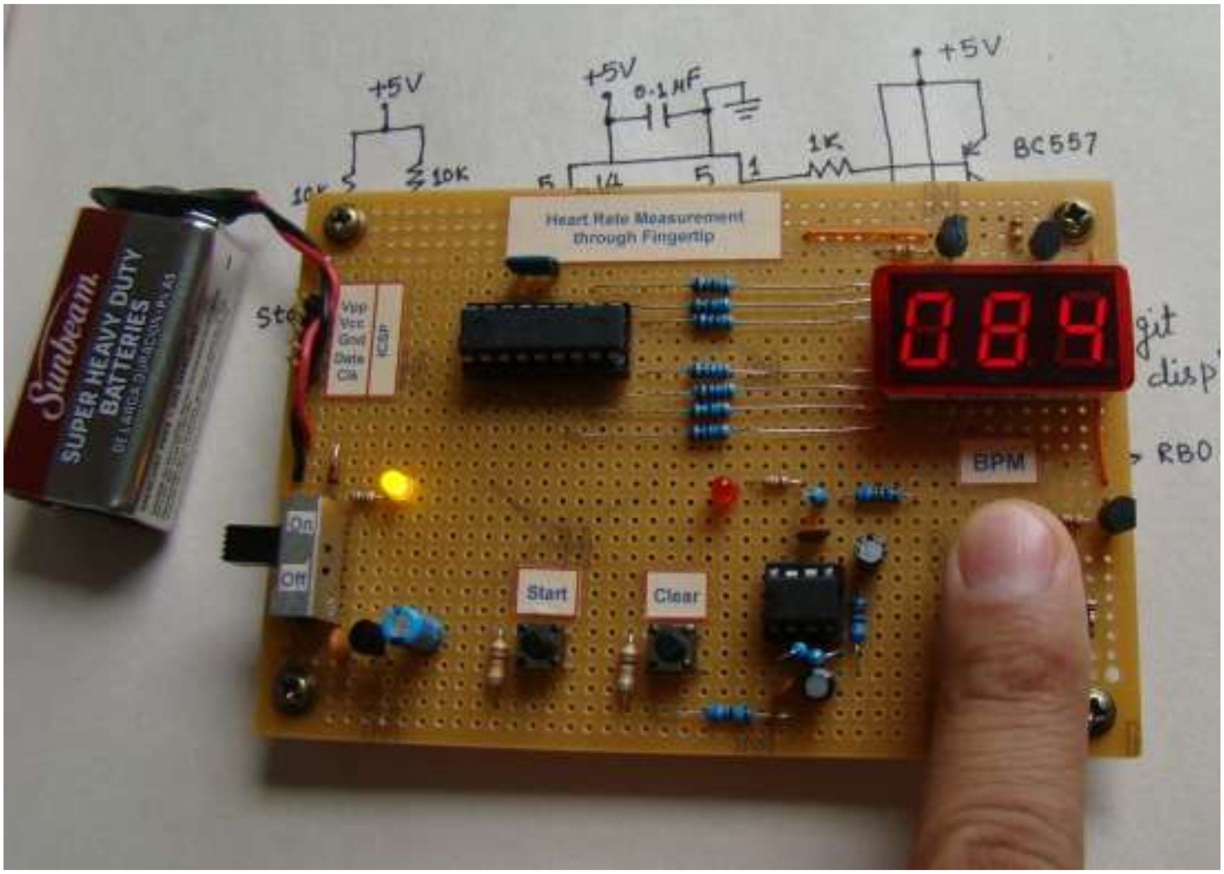


FIGURE 5.1 **TESTING THE SYSTEM**

5.2 IMPORTANT NOTES

I am adding these paragraphs to provide further detail on the sensor and signal conditioning part of this project, as I heard that this might be a tricky part to grasp.

The harder part in this project is the signal conditioning circuit that uses active low pass filters using OpAmps to boost the weak reflected light signal detected by the photo diode. The IR transmitting diode and the photo diode are placed closely but any direct crosstalk between the two is avoided. Look at the following pictures to see how direct infrared light has been blocked from falling into the adjacent photo diode. Besides, surrounding the sensor with an opaque material makes the sensor system more robust to changing ambient light condition. Separate IR diode and photo diode have been used, but you can buy reflective optical sensor systems that have both the diodes assembled together. Here’s an example from Tayda Electronics.

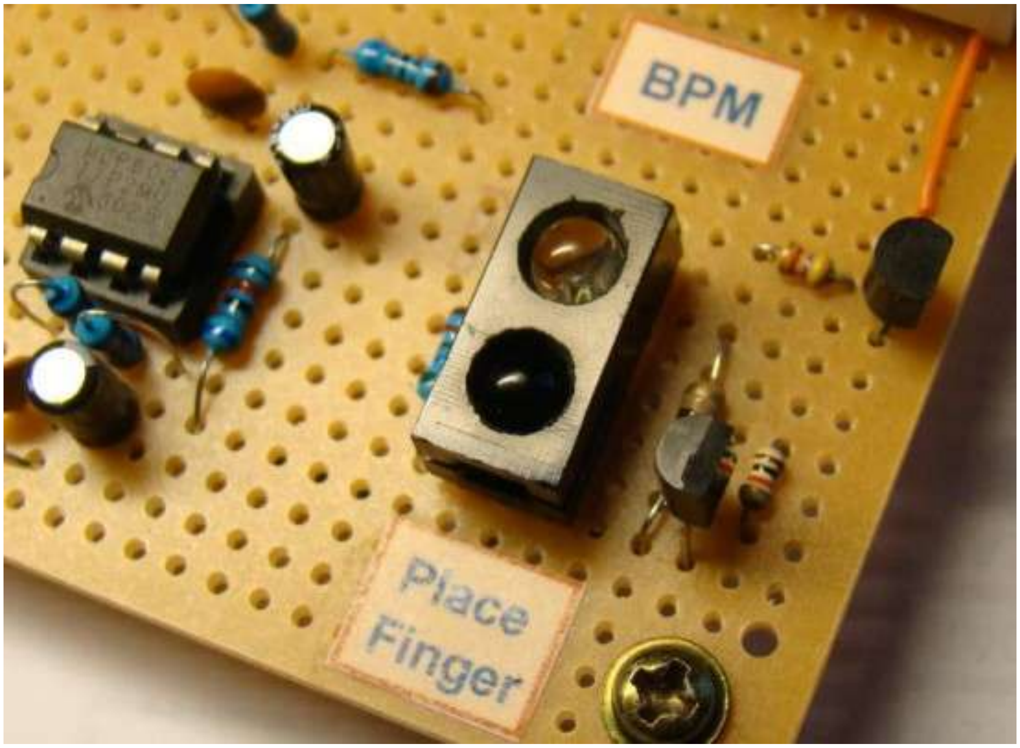
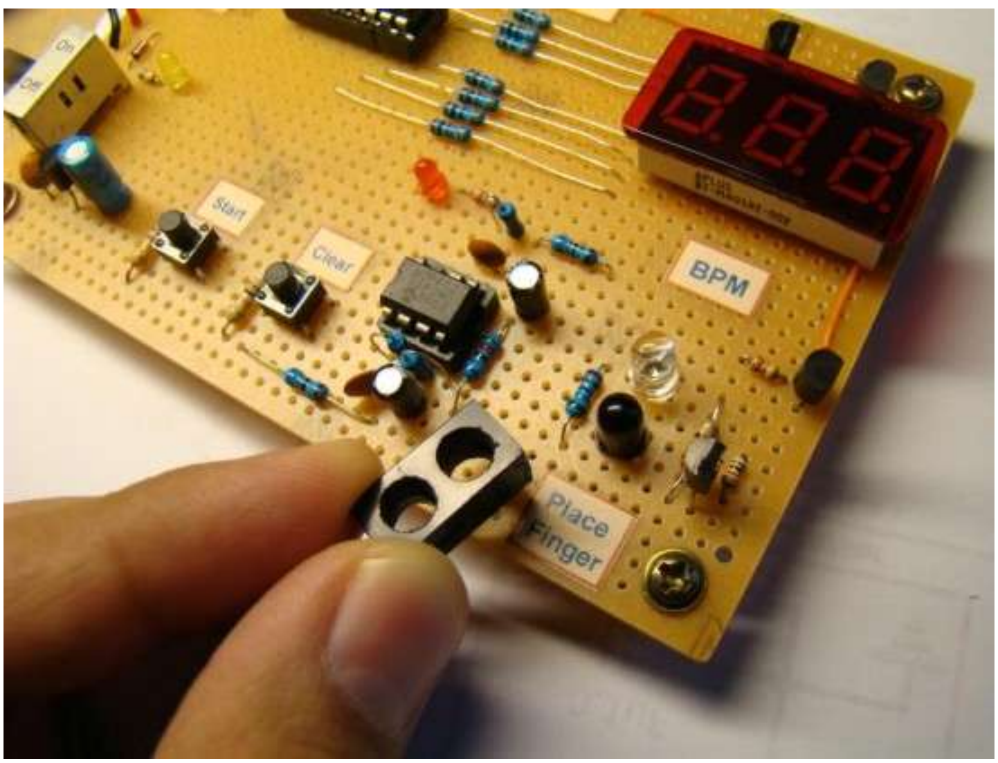
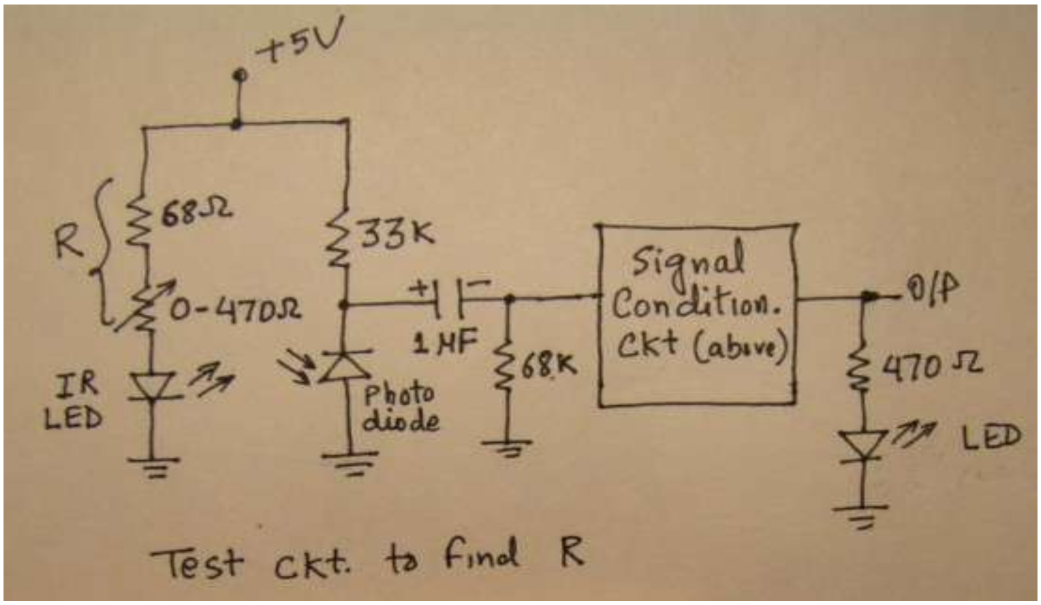


FIGURE 5.2 **PLACING THE FINGER ON THE SENSOR**



The 150 Ω resistance in series with the IR diode is to limit the current and hence the intensity of the transmitted infrared light. The intensity of IR light should not be too high otherwise the reflected light will be sufficient enough to saturate the photo detecting diode all the time and no signal will exist. The value of this current limiting resistor could be different for different IR diodes, depending upon their specifications. Here's a practical test circuit that I used to find the appropriate value of the series resistor for the IR diode I plan to use.



First a 68 Ω resistor is used with a 470 Ω potentiometer in series with the IR diode. Placing a fingertip over the sensor assembly, the potentiometer is slowly varied till the output LED blinking with heartbeat is found. Then the equivalent resistance R is measured and the 68 Ω and the potentiometer are replaced with a single resistor closest to R. But you can also keep the potentiometer in your circuit so that you can always adjust it when needed. You should keep your fingertip very still over the sensor while testing. Once you see the pulses at the output of the signal conditioning circuit, you can feed them to a microcontroller to count and display.

CHAPTER 6

BUILDING THE DEVICE

6.1 INTRODUCTION

This chapter focuses on the actual process followed by my group mates and me in making this device. I will be talking briefly about the hardware and the software. I focused mainly on the software and a little on the hardware, while my friends focused solely on the hardware, nonetheless, this chapter will cover both aspects of this project.

6.2 The Hardware

Figure 6.1 shows the circuit diagram:

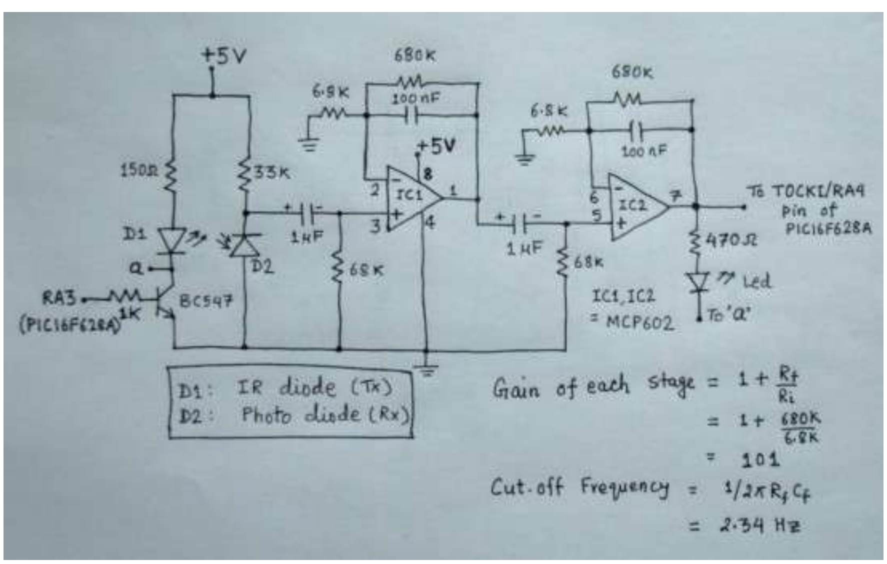


FIGURE 6.1

On the left hand side of the circuit, the infrared LED (D1) and the infrared detector can be seen. The infrared LED is shown with a standard LED symbol. A 150ohm current resisting resistor is used in the LED circuit. The infrared detector is basically a transistor with its base being activated by the infrared signal. The collector of the detector is connected to the supply rail via a 33K resistor. The output of the infrared detector is fed to an amplifier/filter circuit consisting on two OP295 type operational amplifiers. Capacitor-resistor type coupling is used between the stages of the amplifiers.

The first operational amplifier is organized as an inverting amplifier with a gain of about 101, with a 680K resistor used in the feedback loop. A 6.8K resistor is used at the negative input of the operational amplifier. Also, a 100nF capacitor is used as a low pass filter in the feedback loop. Figure 6.2 shows the filtering characteristics of the circuit:

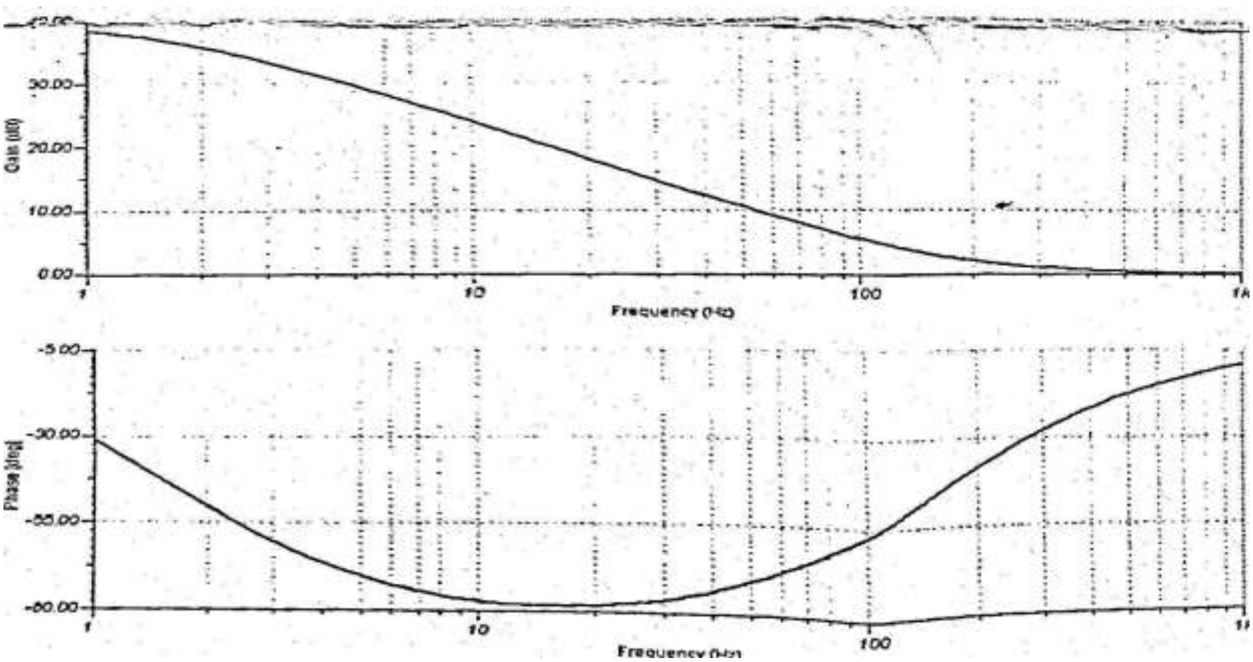


FIGURE 6.2 **FILTERING CHARACTERISTICS OF THE CIRCUIT**

The second operational amplifier is also organized as a non-inverting amplifier. A 680K resistor is used in the feedback path and a 1K resistor used at the negative input if the operational amplifier. The gain of this second stage is also 101. Thus, the overall gain of the amplifier is about 10,000. Since the signal output from the sensor is in microvolts range, it was necessary to use a high gain to boost the signal level so that it can be better observed and used for measurement of heart rate from the finger.

6.3 The Ready for PIC board

The board is equipped with the PIC18F45K22 MCU that is placed in DIP 40 socket and contains male headers and connection pads for all available microcontroller ports. The pins are grouped according to their functions. The MCU becomes pre-programmed with mikroBootloader, but it can also be programmed with mikroProg programmer. During the making of this device, the board was powered with a laptop, since it has a USB-UART module, prototyping area and a power supply circuit.

- Power Supply: Via AC/DC connector 7-23V AC or 9-32V DC.
- Power consumption: 6.2mA in idle state (when on-board modules are off).
- Board dimensions: 141 x 84mm (5.55 x 3.3 inch).
- Weight: 60g (0.13lbs).

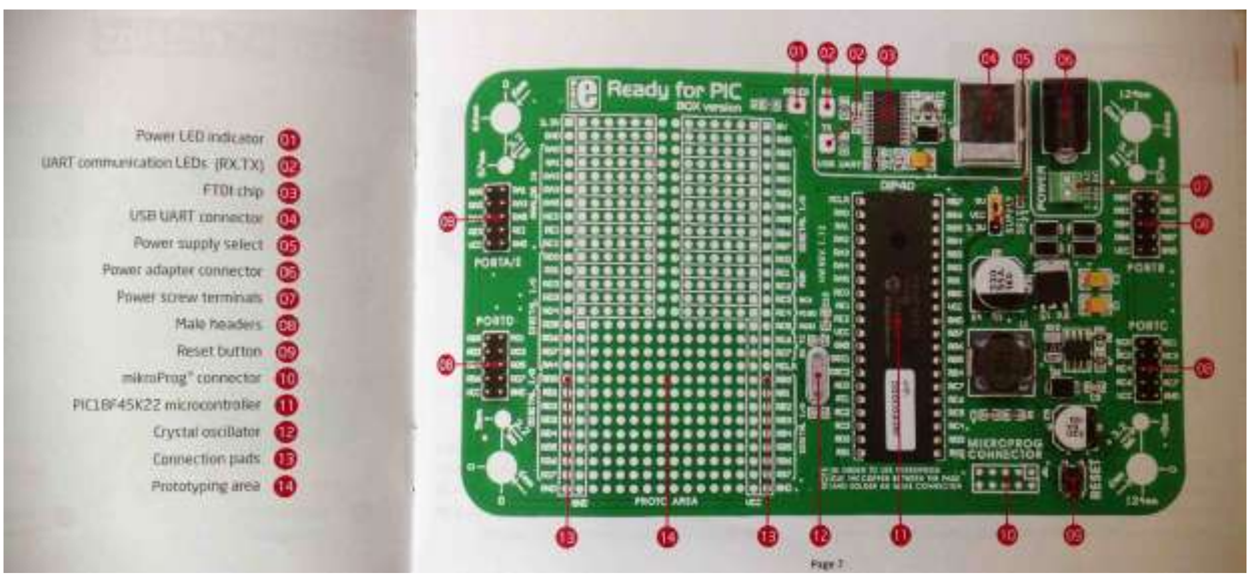
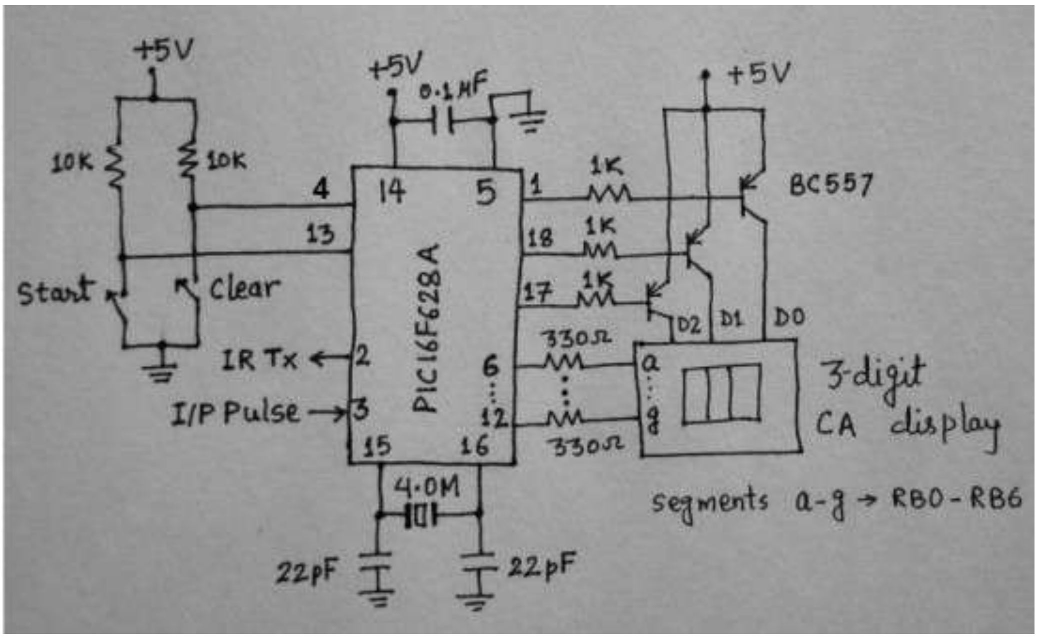


FIGURE 6.3 **THE READY FOR PIC DEVELOPMENT BOARD**

6.4 The complete circuit

Below is a complete circuit diagram of the designed hardware. The PIC 18F45K22 microcontroller runs at 4.0 MHz using an external crystal. The right hand part of the hardware is the microcontroller and the LCD circuit. The output of the amplifier circuit is fed to one of the digital inputs of a PIC microcontroller. The microcontroller calculates the heart rate and displays on the LCD connected to the microcontroller. An LED is used at the input of the microcontroller circuit so that heart beats can be seen by the flashing LED. The measurement begins when the push-button switch is pressed.



6.5 The Software

The software was developed using the Proton+ Basic compiler. This is a very powerful BASIC compiler for microcontrollers. The operation of the software is described by the simple Program Description Language (PDL) shown below:

BEGIN

Initialize program variables

Configure input-output ports

Display message "**READY**"

Wait until switch is pressed

Sum = 0

DO 3 times

Get count in 10 seconds

Count = 6 * Count

Sum = Sum + Count

ENDDO

Calculate the average, Rate = Sum / 3

Display the average on the LCD

END

If the number of pulse counts in time T is n, then the heart rate per minute is given by N, where,

N = 60n/T

If the duration of a measurement is 10 seconds, then the heart rate is calculated as:

N = 6n

6.6 The program

```
Device = 18F45

Symbol SVIC = PORTB.1

Dim Counter As Byte

Dim Heart As Word

Dim J As Byte              'AN0 Please log in port

TRISB = %00000011          'Wait for 1 second

DelayMS 1000               'write READY message
```

```
Print "READY…"

While SVIC = 1
Wend
Cls
Print "CALCULATING…"
Heart = 0
J = 1
While 1 = 1
      Counter = Counter PORTB.0, 10000     '10 sec
      Counter = 6 * Counter                'heart rate
      Heart = Heart + Counter
      Heart = Heart / J
      Cls
Print "Heart =", Dec Counter," /min"       'show two digits after the point
J = J + 1
Wend
End
```

CHAPTER 7

CONCLUSIONS

The design of the plethysmography instrument has been described in detail. The theory studied before the making of the device is slightly different from the actual device my friends and I made. The device is based on an infrared emitter and an infrared sensor. The sensors are clipped to the finger of a person and as the heart beats, the volume of the blood in the finger changes and the sensor detects the small change. This change is then amplified and fed to a microcontroller based system. He microcontroller calculates the heart rate and displays the result on an LCD every second.

In comparison to the theory (which came before the actual creation of the device), my friends and I improved the device by adding an LCD to the complete circuit. This is where the results are displayed.

There is a lot of room for improvement on this device which can be done by anyone else interested in making it. A few of the possible improvements are:

- A buzzer can be added, so that the heart beat can be heard.
- A real time clock chip can be added do that date and time can be viewed.
- Another LCD (except this time, a graphical one) can be added to show the actual waveform of the heartbeat.
- A flash card memory card interface can be designed so that the heart beats can be stored for future analysis.

REFERENCES

- http://embedded-lab.com
- http://teachmeanatomy.net
- http://www.dummies.com
- http://www.electronics-lab.com
- http://en.wikipedia.org
- Design and development of a heart rate measuring device using fingertip by Hashem, M.M.A. Shams, R. Kader, M.A. Sayed, M.A., International conference on computer and communication engineering, 2010.
- Heart rate measurement from the finger using a low cost microcontroller by **Dogan Ibrahim** and Kadri Buruncuk.
- http://us.oregonscientific.com

- Heart rate measurement from the finger - Miss Yucel's final year project (Computer Engineering Department, Near East University)
- http://www.analog.com/static/imported-files/data_sheets/OP295_495.pdf

APPENDIX A

OP295 DATA SHEET

Dual/Quad Rail-to-Rail

Operational Amplifiers

OP295/OP495

Rev. G

Information furnished by Analog Devices is believed to be accurate and reliable. However, no responsibility is assumed by Analog Devices for its use, nor for any infringements of patents or other rights of third parties that may result from its use. Specifications subject to change without notice. No

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.

Tel: 781.329.4700 www.analog.com

Fax: 781.461.3113

FEATURES

Rail-to-rail output swing

Single-supply operation: 3 V to 36 V

Low offset voltage: 300 µV

Gain bandwidth product: 75 kHz

High open-loop gain: 1000 V/mV

Unity-gain stable

Low supply current/per amplifier: 150 µA maximum

APPLICATIONS

Battery-operated instrumentation

Servo amplifiers

Actuator drives

Sensor conditioners

Power supply control

GENERAL DESCRIPTION

Rail-to-rail output swing combined with dc accuracy are the key features of the OP495 quad and OP295 dual CBCMOS operational amplifiers. By using a bipolar front end, lower noise and higher accuracy than those of CMOS designs have been achieved. Both input and output ranges include the negative

supply, providing the user with zero-in/zero-out capability. For
users of 3.3 V systems such as lithium batteries, the OP295/OP495
are specified for 3 V operation.

Maximum offset voltage is specified at 300 μV for 5 V operation,
and the open-loop gain is a minimum of 1000 V/mV. This yields
performance that can be used to implement high accuracy systems,
even in single-supply designs.

The ability to swing rail-to-rail and supply 15 mA to the load
makes the OP295/OP495 ideal drivers for power transistors and
H bridges. This allows designs to achieve higher efficiencies and
to transfer more power to the load than previously possible
without the use of discrete components.

For applications such as transformers that require driving
inductive loads, increases in efficiency are also possible.

Stability while driving capacitive loads is another benefit of this
design over CMOS rail-to-rail amplifiers. This is useful for
driving coax cable or large FET transistors. The OP295/OP495
are stable with loads in excess of 300 pF.

PIN CONFIGURATIONS

OUT A 1

–IN A 2

+IN A 3

V– 4

8 V+

7 OUT B

6 –IN B

5 +IN B

OP295

TOP VIEW

(Not to Scale)

00331-001

Figure 1. 8-Lead Narrow-Body SOIC_N

S Suffix (R-8)

OUT A 1

–IN A 2

+IN A 3

V– 4

8 V+

7 OUT B

6 –IN B

5 +IN B

OP295

00331-002

Figure 2. 8-Lead PDIP

P Suffix (N-8)

OUT A 1

–IN A 2

+IN A 3

V+ 4

14 OUT D

13 –IN D

12 +IN D

11 V–

+IN B 5

–IN B 6

OUT B 7

10 +IN C

9 –IN C

8 OUT C

OP495

00331-003

Figure 3. 14-Lead PDIP

P Suffix (N-14)

OUT A 1

–IN A 2

+IN A 3

V+ 4

16 OUT D

15 –IN D

14 +IN D

13 V–

+IN B 5 12 +IN C

–IN B 6 11 –IN C

OUT B 7 10 OUT C

NC 8 9 NC

NC = NO CONNECT

OP495

TOP VIEW

(Not to Scale)

00331-004

Figure 4. 16-Lead SOIC_W

S Suffix (RW-16)

The OP295 and OP495 are specified over the extended industrial (−40°C to +125°C) temperature range. The OP295 is

available in 8-lead PDIP and 8-lead SOIC_N surface-mount

packages. The OP495 is available in 14-lead PDIP and 16-lead

SOIC_W surface-mount packages. OP295/OP495

Rev. G | Page 2 of 16

TABLE OF CONTENTS

Features 1

Applications 1

General Description 1

Pin Configurations 1

Revision History 2

Specifications 3

Electrical Characteristics 3

Absolute Maximum Ratings 5

Thermal Resistance 5

ESD Caution 5

Typical Performance Characteristics 6

Applications 9

Rail-to-Rail Application Information 9

Low Drop-Out Reference 9

Low Noise, Single-Supply Preamplifier 9

Driving Heavy Loads 10

Direct Access Arrangement 10

Single-Supply Instrumentation Amplifier 10

Single-Supply RTD Thermometer Amplifier 11

Cold Junction Compensated, Battery-Powered

Thermocouple Amplifier 11

5 V Only, 12-Bit DAC That Swings 0 V to 4.095 V 11

4 mA to 20 mA Current-Loop Transmitter 12

3 V Low Dropout Linear Voltage Regulator 12

Low Dropout, 500 mA Voltage Regulator with Foldback

Current Limiting 12

Square Wave Oscillator 13

Single-Supply Differential Speaker Driver 13

High Accuracy, Single-Supply, Low Power Comparator 13

Outline Dimensions 14

Ordering Guide 16

REVISION HISTORY

8/09—Rev. F to Rev. G

Added Figure 18 8

Updated Outline Dimensions 17

3/08—Rev. E to Rev. F

Changes to Offset Voltage Unit in Table 1 3

Updated Outline Dimensions 14

Changes to Ordering Guide 16

5/06—Rev. D to Rev. E

Updated Format .... Universal

Changes to Features 1

Changes to Pin Connections 1

Updated Outline Dimensions 14

Changes to Ordering Guide 15

2/04—Rev. C to Rev. D

Changes to General Description 1

Changes to Specifications 2

Changes to Absolute Maximum Ratings 4

Changes to Ordering Guide 4

Updated Outline Dimensions 12

3/02—Rev. B to Rev. C

Figure changes to Pin Connections 1

Deleted OP295GBC and OP495GBC from Ordering Guide 3

Deleted Wafer Test Limits Table 3

Changes to Absolute Maximum Ratings 4

Deleted Dice Characteristics 4 OP295/OP495

Rev. G | Page 3 of 16

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS

VS = 5.0 V, VCM = 2.5 V, TA = 25°C, unless otherwise noted.

Table 1.

Parameter Symbol Conditions Min Typ Max Unit

INPUT CHARACTERISTICS

Offset Voltage VOS 30 300 µV

−40°C ≤ T

A ≤ +125°C 800 µV

Input Bias Current I

B 8 20 nA

−40°C ≤ T

A ≤ +125°C 30 nA

Input Offset Current IOS ±1 ±3 nA

−40°C ≤ T

A ≤ +125°C ±5 nA

Input Voltage Range V

CM 0 4.0 V

Common-Mode Rejection Ratio CMRR 0 V ≤ VCM ≤ 4.0 V, −40°C ≤ TA ≤ +125°C 90 110 dB

Large Signal Voltage Gain AVO RL = 10 kΩ, 0.005 ≤ VOUT ≤ 4.0 V 1000 10,000 V/mV

RL = 10 kΩ, −40°C ≤ TA ≤ +125°C 500 V/mV

Offset Voltage Drift ΔVOS/ΔT 1 5 µV/°C

OUTPUT CHARACTERISTICS

Output Voltage Swing High VOH RL = 100 kΩ to GND 4.98 5.0 V

RL = 10 kΩ to GND 4.90 4.94 V

IOUT = 1 mA, −40°C ≤ TA ≤ +125°C 4.7 V

Output Voltage Swing Low VOL RL = 100 kΩ to GND 0.7 2 mV

RL = 10 kΩ to GND 0.7 2 mV

IOUT = 1 mA, −40°C ≤ TA ≤ +125°C 90 mV

Output Current IOUT ±11 ±18 mA

POWER SUPPLY

Power Supply Rejection Ratio PSRR ±1.5 V ≤ VS ≤ ±15 V 90 110 dB

±1.5 V ≤ VS ≤ ±15 V, –40°C ≤ TA ≤ +125°C 85 dB

Supply Current per Amplifier I

SY VOUT = 2.5 V, RL = ∞, −40°C ≤ TA ≤ +125°C 150 µA

DYNAMIC PERFORMANCE

Slew Rate SR RL = 10 kΩ 0.03 V/µs

Gain Bandwidth Product GBP 75 kHz

Phase Margin θO 86 Degrees

NOISE PERFORMANCE

Voltage Noise e

n p-p 0.1 Hz to 10 Hz 1.5 µV p-p

Voltage Noise Density e

n f = 1 kHz 51 nV/√Hz

Current Noise Density i

n f = 1 kHz <0.1 pA/√Hz

VS = 3.0 V, VCM = 1.5 V, TA = 25°C, unless otherwise noted.

Table 2.

Parameter Symbol Conditions Min Typ Max Unit

INPUT CHARACTERISTICS

Offset Voltage VOS 100 500 µV

Input Bias Current I

B 8 20 nA

Input Offset Current IOS ±1 ±3 nA

Input Voltage Range V

CM 0 2.0 V

Common-Mode Rejection Ration CMRR 0 V ≤ VCM ≤ 2.0 V, −40°C ≤ TA ≤ +125°C 90 110 dB

Large Signal Voltage Gain AVO RL = 10 kΩ 750 V/mV

Offset Voltage Drift ΔVOS/ΔT 1 µV/°C OP295/OP495

Rev. G | Page 4 of 16

Parameter Symbol Conditions Min Typ Max Unit

OUTPUT CHARACTERISTICS

Output Voltage Swing High VOH RL = 10 kΩ to GND 2.9 V

Output Voltage Swing Low VOL RL = 10 kΩ to GND 0.7 2 mV

POWER SUPPLY

Power Supply Rejection Ratio PSRR ±1.5 V ≤ VS ≤ ±15 V 90 110 dB

±1.5 V ≤ VS ≤ ±15 V, −40°C ≤ TA ≤ +125°C 85 dB

Supply Current per Amplifier I

SY VOUT = 1.5 V, RL = ∞, −40°C ≤ TA ≤ +125°C 150 µA

DYNAMIC PERFORMANCE

Slew Rate SR RL = 10 kΩ 0.03 V/µs

Gain Bandwidth Product GBP 75 kHz

Phase Margin θO 85 Degrees

NOISE PERFORMANCE

Voltage Noise e

n p-p 0.1 Hz to 10 Hz 1.6 µV p-p

Voltage Noise Density e

n f = 1 kHz 53 nV/√Hz

Current Noise Density i

n f = 1 kHz <0.1 pA/√Hz

VS = ±15.0 V, TA = 25°C, unless otherwise noted.

Table 3.

Parameter Symbol Conditions Min Typ Max Unit

INPUT CHARACTERISTICS

Offset Voltage VOS 300 500 µV

−40°C ≤ T

A ≤ +125°C 800 µV

Input Bias Current I

B

V

CM = 0 V 7 20 nA

V

CM = 0 V, −40°C ≤ TA ≤ +125°C 30 nA

Input Offset Current IOS V

CM = 0 V ±1 ±3 nA

V

CM = 0 V, −40°C ≤ TA ≤ +125°C ±5 nA

Input Voltage Range V

CM −15 +13.5 V

Common-Mode Rejection Ratio CMRR −15.0 V ≤ VCM ≤ +13.5 V, −40°C ≤ TA ≤ +125°C 90 110 dB

Large Signal Voltage Gain AVO RL = 10 kΩ 1000 4000 V/mV

Offset Voltage Drift ΔVOS/ΔT 1 µV/°C

OUTPUT CHARACTERISTICS

Output Voltage Swing High VOH RL = 100 kΩ to GND 14.95 V

RL = 10 kΩ to GND 14.80 V

Output Voltage Swing Low VOL RL = 100 kΩ to GND −14.95 V

RL = 10 kΩ to GND −14.85 V

Output Current IOUT ±15 ±25 mA

POWER SUPPLY

Power Supply Rejection Ratio PSRR VS = ±1.5 V to ±15 V 90 110 dB

VS = ±1.5 V to ±15 V, −40°C ≤ TA ≤ +125°C 85 dB

Supply Current per Amplifier I

SY VO = 0 V, RL = ∞, VS = ±18 V, −40°C ≤ TA ≤ +125°C 175 µA

Supply Voltage Range VS

3 (± 1.5) 36 (± 18) V

DYNAMIC PERFORMANCE

Slew Rate SR RL = 10 kΩ 0.03 V/µs

Gain Bandwidth Product GBP 85 kHz

Phase Margin θO 83 Degrees

NOISE PERFORMANCE

Voltage Noise e

n p-p 0.1 Hz to 10 Hz 1.25 µV p-p

Voltage Noise Density e

n f = 1 kHz 45 nV/√Hz

Current Noise Density i

n f = 1 kHz <0.1 pA/√Hz OP295/OP495

Rev. G | Page 5 of 16

ABSOLUTE MAXIMUM RATINGS

THERMAL RESISTANCE

Table 4.

Parameter1

Rating

Supply Voltage ±18 V

Input Voltage ±18 V

Differential Input Voltage2

36 V

Output Short-Circuit Duration Indefinite

Storage Temperature Range

P, S Packages −65°C to +150°C

Operating Temperature Range

OP295G, OP495G –40°C to +125°C

Junction Temperature Range

P, S Packages –65°C to +150°C

Lead Temperature (Soldering, 60 sec) 300°C

θJA is specified for worst case mounting conditions; that is, θJA

is specified for device in socket for PDIP; θJA is specified for

device soldered to printed circuit board for SOIC package.

Table 5. Thermal Resistance

Package Type θJA θJC Unit

8-Lead PDIP (N-8) 103 43 °C/W

8-Lead SOIC_N (R-8) 158 43 °C/W

14-Lead PDIP (N-14) 83 39 °C/W

16-Lead SOIC_W (RW-16) 98 30 °C/W

ESD CAUTION

1

Absolute maximum ratings apply to packaged parts, unless otherwise noted.

2

For supply voltages less than ±18 V, the absolute maximum input voltage is

equal to the supply voltage.

Stresses above those listed under Absolute Maximum Ratings

may cause permanent damage to the device. This is a stress

rating only; functional operation of the device at these or any

other conditions above those indicated in the operational

section of this specification is not implied. Exposure to absolute

maximum rating conditions for extended periods may affect

device reliability. OP295/OP495

Rev. G | Page 6 of 16

TYPICAL PERFORMANCE CHARACTERISTICS

SUPPLY CURRENT (µA)

140

20

100

80

40

–25

60

–50

120

100

0 25 50 75

TEMPERATURE (°C)

VS = 36V

VS = 5V

VS = 3V

00331-005

Figure 5. Supply Current Per Amplifier vs. Temperature

15.2

–15.2

100

–14.6

–15.0

–25

–14.8

–50

14.2

–14.4

14.4

14.6

14.8

15.0

0 25 50 75

– OUTPUT SWING (V) + OUTPUT SWING (V)

VS = ±15V RL = 100kΩ

RL = 10kΩ

RL = 2kΩ

RL = 100kΩ

RL = 2kΩ

TEMPERATURE (°C)

RL = 10kΩ

00331-006

Figure 6. Output Voltage Swing vs. Temperature

3.1

2.5

100

2.8

2.6

–25

2.7

–50

3.0

2.9

0 25 50 75

TEMPERATURE (°C)

OUTPUT VOLTAGE SWING (V)

VS = 3V

RL = 2kΩ

RL = 10kΩ

RL = 100kΩ

00331-007

Figure 7. Output Voltage Swing vs. Temperature

200

0

250

50

25

–250 –200

100

75

125

150

175

–150 –50–100 0 20015010050

UNITS

INPUT OFFSET VOLTAGE (µV)

VS = 5V

T

A = 25°C

BASED ON 600 OP AMPS

00331-008

Figure 8. OP295 Input Offset (VOS) Distribution

UNITS

250

0

3.2

75

25

0.4

50

0

150

100

125

175

200

225

0.8 1.2 1.6 2.0 2.4 2.8

T

CV

OS (µV/°C)

VS = 5V

–40°C ≤ T

A ≤ +85°C

BASED ON 600 OP AMPS

00331-009

Figure 9. OP295 TCVOS Distribution

5.1

4.5

100

4.8

4.6

–25

4.7

–50

5.0

4.9

0 25 50 75

OUTPUT VOLTAGE SWING (V)

VS = 5V

TEMPERATURE (°C)

RL = 100kΩ

RL = 10kΩ

RL = 2kΩ

00331-010

Figure 10. Output Voltage Swing vs. Temperature OP295/OP495

Rev. G | Page 7 of 16

500

0

300

150

50

–50

100

–100

300

200

250

350

400

450

0 50 100 150 200 250

UNITS

VS = 5V

T

A = 25°C

BASED ON 1200 OP AMPS

INPUT OFFSET VOLTAGE (µV) 00331-011

Figure 11. OP495 Input Offset (VOS) Distribution

450

400

350

300

250

200

150

100

50

UNITS

500

0

0 2 0.4 0.8 1.2 1.6 2.0 2.4 .8 3.2

T

CV

OS (µV/°C)

VS = 5V

–40°C ≤ T

A ≤ +85°C

BASED ON 1200 OP AMPS

00331-012

Figure 12. OP495 TCVOS Distribution

00331-033

20

0

100

12

4

–25

8

–50

16

0 25 50 75

INPUT BIAS CURRENT (nA)

TEMPERATURE (°C)

VS = 5V

Figure 13. Input Bias Current vs. Temperature

TEMPERATURE (°C)

40

0

100

10

5

–50 –25

20

15

25

30

35

0 25 50 75

OUTPUT CURRENT (mA)

VS = ±15V

VS = +5V

SOURCE

SINK

SOURCE

SINK

00331-013

Figure 14. Output Current vs. Temperature

100

10

1

TEMPERATURE (°C)

OPEN-LOOP GAIN (V/μV)

VS = ±15V

V

O = ±10V

RL = 2kΩ

RL = 10kΩ

RL = 100kΩ

–50 –25 0 25 50 75 100

00331-014

Figure 15. Open-Loop Gain vs. Temperature

12

0

100

6

2

–25

4

–50

10

8

0 25 50 75

VS = 5V

V

O = 4V

RL = 2kΩ

RL = 10kΩ

RL = 100kΩ

OPEN-LOOP GAIN (V/μV)

TEMPERATURE (°C) 00331-015

Figure 16. Open-Loop Gain vs. Temperature OP295/OP495

Rev. G | Page 8 of 16

OUTPUT VOLTAGE Δ TO RAIL

LOAD CURRENT

SINK

SOURCE

VS = 5V

T

A = 25°C

1V

100μV

100mV

10mV

1mV

1μA 10μA 100μA 1mA 10mA 00331-016

Figure 17. Output Voltage to Supply Rail vs. Load Current

–40

–20

0

20

40

60

80

100

120

–40

–20

0

20

40

60

80

100

120

0.01 0.1 1 10 100 1k

MAGNITUDE (dB)

PHASE (°)

FREQUENCY (KHz)

OP295

T

A = 25°C

VSY = ±15V

00331-034

Figure 18. OP295 Gain and Phase vs. Frequency OP295/OP495

Rev. G | Page 9 of 16

APPLICATIONS

RAIL-TO-RAIL APPLICATION INFORMATION

The OP295/OP495 have a wide common-mode input range

extending from ground to within about 800 mV of the positive

supply. There is a tendency to use the OP295/OP495 in buffer

applications where the input voltage could exceed the commonmode input range. This can initially appear to work because of

the high input range and rail-to-rail output range. But above the

common-mode input range, the amplifier is, of course, highly

nonlinear. For this reason, there must be some minimal amount

of gain when rail-to-rail output swing is desired. Based on the

input common-mode range, this gain should be at least 1.2.

LOW DROP-OUT REFERENCE

The OP295/OP495 can be used to gain up a 2.5 V or other low

voltage reference to 4.5 V for use with high resolution ADCs

that operate from 5 V only supplies. The circuit in Figure 19

supplies up to 10 mA. Its no-load drop-out voltage is only

20 mV. This circuit supplies over 3.5 mA with a 5 V supply.

4

2

6

–

+ +

1/2

OP295/OP495

V

OUT = 4.5V

5V

5V

16kΩ

10Ω

20kΩ

0.001µF

REF43 1µF TO

10µF

00331-017

Figure 19. 4.5 V, Low Drop-Out Reference

LOW NOISE, SINGLE-SUPPLY PREAMPLIFIER

Most single-supply op amps are designed to draw low supply

current at the expense of having higher voltage noise. This tradeoff

may be necessary because the system must be powered by a

battery. However, this condition is worsened because all circuit

resistances tend to be higher; as a result, in addition to the op

amp's voltage noise, Johnson noise (resistor thermal noise) is

also a significant contributor to the total noise of the system.

The choice of monolithic op amps that combine the characteristics of low noise and single-supply operation is rather limited.

Most single-supply op amps have noise on the order of 30 nV/√Hz

to 60 nV/√Hz, and single-supply amplifiers with noise below

5 nV/√Hz do not exist.

To achieve both low noise and low supply voltage operation,

discrete designs may provide the best solution. The circuit in

Figure 20 uses the OP295/OP495 rail-to-rail amplifier and a

matched PNP transistor pair—the MAT03—to achieve zeroin/zero-out single-supply operation with an input voltage noise

of 3.1 nV/√Hz at 100 Hz.

R5 and R6 set the gain of 1000, making this circuit ideal for

maximizing dynamic range when amplifying low level signals in

single-supply applications. The OP295/OP495 provide rail-torail output swings, allowing this circuit to operate with 0 V to

5 V outputs. Only half of the OP295/OP495 is used, leaving the

other uncommitted op amp for use elsewhere.

1

2

3 4

– 8

+

+ –

2 6

3 5

1 7

Q1 MAT03 Q2

0.1µF

LED R1

R3 R4

OP295/OP495

10µF

R6

10Ω

V

OUT

C2

10µF

R5

10kΩ

Q2

2N3906

R7

510Ω

R2

27kΩ R8

100Ω

C1

1500pF

VIN

00331-018

Figure 20. Low Noise Single-Supply Preamplifier

The input noise is controlled by the MAT03 transistor pair

and the collector current level. Increasing the collector current

reduces the voltage noise. This particular circuit was tested

with 1.85 mA and 0.5 mA of current. Under these two cases,

the input voltage noise was 3.1 nV/√Hz and 10 nV/√Hz, respectively. The high collector currents do lead to a tradeoff in supply

current, bias current, and current noise. All of these parameters increase with increasing collector current. For example, typically the MAT03 has an hFE = 165. This leads to bias currents of 11 µA and 3 µA, respectively.

Based on the high bias currents, this circuit is best suited for applications with low source impedance such as magnetic pickups or low impedance strain gauges. Furthermore, a high source impedance degrades the noise performance. For example, a 1 kΩ resistor generates 4 nV/√Hz of broadband noise, which is already greater than the noise of the preamp.

The collector current is set by R1 in combination with the LED and Q2. The LED is a 1.6 V Zener diode that has a temperature coefficient close to that of the Q2 base-emitter junction, which provides a constant 1.0 V drop across R1. With R1 equal to 270 Ω, the tail current is 3.7 mA and the collector current is half that, or 1.85 mA. The value of R1 can be altered to adjust the collector current. When R1 is changed, R3 and R4 should also be adjusted. To maintain a common-mode input range that includes ground, the collectors of the Q1 and Q2 should not go above 0.5 V; otherwise, they could saturate. Thus, R3 and R4 must be small enough to prevent this condition. Their values and the overall performance for two different values of R1 are summarized in Table 6. OP295/OP495

Rev. G | Page 10 of 16

Finally, the potentiometer, R8, is needed to adjust the offset voltage to null it to zero. Similar performance can be obtained using an OP90 as the output amplifier with a savings of about

185 µA of supply current. However, the output swing does not

include the positive rail, and the bandwidth reduces to approximately 250 Hz.

Table 6. Single-Supply Low Noise Preamp Performance

I

C = 1.85 mA I

C = 0.5 mA

R1 270 Ω 1.0 kΩ

R3, R4 200 Ω 910 Ω

e

n @ 100 Hz 3.15 nV/√Hz 8.6 nV/√Hz

e

n @ 10 Hz 4.2 nV/√Hz 10.2 nV/√Hz

I

SY 4.0 mA 1.3 mA

I

B 11 µA 3 µA

Bandwidth 1 kHz 1 kHz

Closed-Loop Gain 1000 1000

DRIVING HEAVY LOADS

The OP295/OP495 are well suited to drive loads by using a

power transistor, Darlington, or FET to increase the current to

the load. The ability to swing to either rail can assure that the

device is turned on hard. This results in more power to the load

and an increase in efficiency over using standard op amps with their limited output swing. Driving power FETs is also possible

with the OP295/OP495 because of their ability to drive capacitive loads of several hundred picofarads without oscillating.

Without the addition of external transistors, the OP295/OP495

can drive loads in excess of ±15 mA with ±15 V or +30 V

supplies. This drive capability is somewhat decreased at lower

supply voltages. At ±5 V supplies, the drive current is ±11 mA.

Driving motors or actuators in two directions in a single-supply

application is often accomplished using an H bridge. The

principle is demonstrated in Figure 21. From a single 5 V

supply, this driver is capable of driving loads from 0.8 V to

4.2 V in both directions. Figure 22 shows the voltages at the

inverting and noninverting outputs of the driver. There is a

small crossover glitch that is frequency-dependent; it does not

cause problems unless used in low distortion applications, such

as audio. If this is used to drive inductive loads, diode clamps

should be added to protect the bridge from inductive kickback.

10kΩ

1.67V

2N2222 2N2222

OUTPUTS

2N2907

2N2907

5V

10kΩ 10kΩ

0 ≤ VIN ≤ 2.5V 5kΩ

–

+

–

+

00331-019

Figure 21. H Bridge

10

90

100

0%

2V 2V 1ms 00331-020

Figure 22. H Bridge Outputs

DIRECT ACCESS ARRANGEMENT

The OP295/OP495 can be used in a single-supply direct access

arrangement (DAA), as shown in Figure 23. This figure shows

a portion of a typical DM capable of operating from a single 5 V

supply, and it may also work on 3 V supplies with minor modifications. Amplifier A2 and Amplifier A3 are configured so that

the transmit signal, TxA, is inverted by A2 and is not inverted

by A3. This arrangement drives the transformer differentially so

the drive to the transformer is effectively doubled over a single

amplifier arrangement. This application takes advantage of the

ability of the OP295/OP495 to drive capacitive loads and to save

power in single-supply applications.

–

+

–

2.5V REF +

A3

750pF

A1

37.4kΩ

390pF

RxA

TxA

A2

3.3kΩ 20kΩ

475Ω

22.1kΩ

20kΩ

20kΩ

20kΩ

20kΩ

0.033µF 1:1

–

+

0.0047µF

OP295/

OP495

OP295/

OP495

OP295/

OP495

0.1µF

0.1µF

00331-021

Figure 23. Direct Access Arrangement

SINGLE-SUPPLY INSTRUMENTATION AMPLIFIER

The OP295/OP495 can be configured as a single-supply

instrumentation amplifier, as shown in Figure 24. For this

example, VREF is set equal to V+/2, and VO is measured with

respect to VREF. The input common-mode voltage range

includes ground, and the output swings to both rails. OP295/OP495

Rev. G | Page 11 of 16

V+

–

+

–

+

5

3

2

1

6

8

4

7

1/2

OP295/

OP495

1/2

OP295/

OP495

+

–

VIN

V

O

R4

100kΩ

R3

20kΩ

R2

20kΩ

R1

100kΩ

V

REF R

G

V

O = (

5 + 200kΩ

)

VIN + VREF R

G 00331-022

Figure 24. Single-Supply Instrumentation Amplifier

Resistor RG sets the gain of the instrumentation amplifier.

Minimum gain is 6 (with no RG). All resistors should be matched

in absolute value as well as temperature coefficient to maximize

common-mode rejection performance and minimize drift. This

instrumentation amplifier can operate from a supply voltage as

low as 3 V.

SINGLE-SUPPLY RTD THERMOMETER AMPLIFIER

This RTD amplifier takes advantage of the rail-to-rail swing of

the OP295/OP495 to achieve a high bridge voltage in spite of a

low 5 V supply. The OP295/OP495 amplifier servos a constant

200 µA current to the bridge. The return current drops across

the parallel resistors 6.19 kΩ and 2.55 MΩ, developing a voltage

that is servoed to 1.235 V, which is established by the AD589

band gap reference. The 3-wire RTD provides an equal line

resistance drop in both 100 Ω legs of the bridge, thus improving

the accuracy.

The AMP04 amplifies the differential bridge signal and converts

it to a single-ended output. The gain is set by the series resistance of the 332 Ω resistor plus the 50 Ω potentiometer. The

gain scales the output to produce a 4.5 V full scale. The 0.22 µF

capacitor to the output provides a 7 Hz low-pass filter to keep noise at a minimum.

ZERO ADJ

AD589

37.4kΩ

5V

1.235

3

2

4

5

6

8

1

7

5V

AMP04

50Ω

332Ω

0.22µF

V

O

–

+

2 3

1

+–

200Ω

10-TURNS

26.7kΩ

0.5%

26.7kΩ

0.5%

100Ω

RTD

100Ω

0.5%

2.55MΩ

1%

6.19kΩ

1%

1/2

OP295/

OP495

4.5V = 450°C

0V = 0°C

00331-023

Figure 25. Low Power RTD Amplifier

COLD JUNCTION COMPENSATED, BATTERYPOWERED THERMOCOUPLE AMPLIFIER

The 150 μA quiescent current per amplifier consumption of the

OP295/OP495 makes them useful for battery-powered temperature measuring instruments. The K-type thermocouple terminates into an isothermal block where the terminated junctions' ambient temperatures can be continuously monitored and corrected by summing an equal but opposite thermal EMF to the amplifier, thereby canceling the error introduced by the cold junctions.

AD589

ALUMEL

CHROMEL

AL

CR

1N914

1.235V 24.9kΩ

9V

1.33MΩ

20kΩ

2

3 4

8

–

+

–

+

–

+

COLD 1

JUNCTIONS

ISOTHERMAL

BLOCK

K-TYPE

THERMOCOUPLE

40.7µV/°C

V

O

5V = 500°C

0V = 0°C

OP295/

OP495

SCALE

ADJUST

7.15kΩ

1%

1.5MΩ

1%

24.9kΩ

1%

475Ω

1%

2.1kΩ

1%

24.3kΩ

1%

4.99kΩ

1%

500Ω

10-TURN

ZERO

ADJUST

00331-024

Figure 26. Battery-Powered, Cold-Junction Compensated

Thermocouple Amplifier

To calibrate, immerse the thermocouple measuring junction in

a 0°C ice bath and adjust the 500 Ω zero-adjust potentiometer

to 0 V out. Then immerse the thermocouple in a 250°C temperature bath or oven and adjust the scale-adjust potentiometer

for an output voltage of 2.50 V, which is equivalent to 250°C.

Within this temperature range, the K-type thermocouple is

quite accurate and produces a fairly linear transfer characteristic.

Accuracy of ±3°C is achievable without linearization.

Even if the battery voltage is allowed to decay to as low as 7 V,

the rail-to-rail swing allows temperature measurements to 700°C.

However, linearization may be necessary for temperatures above

250°C, where the thermocouple becomes rather nonlinear. The

circuit draws just under 500 μA supply current from a 9 V

battery.

5 V ONLY, 12-BIT DAC THAT SWINGS 0 V TO 4.095 V

Figure 27 shows a complete voltage output DAC with wide output voltage swing operating off a single 5 V supply. The

serial input, 12-bit DAC is configured as a voltage output device

with the 1.235 V reference feeding the current output pin (IOUT)

of the DAC. The VREF, which is normally the input, now becomes

the output.

The output voltage from the DAC is the binary weighted voltage

of the reference, which is gained up by the output amplifier such

that the DAC has a 1 mV per bit transfer function. OP295/OP495

Rev. G | Page 12 of 16

1.23V

AD589

3

LD

2

1

3

2

4

1

8

5V 8

4 765

5V 5V

DIGITAL

CONTROL

TOTAL POWER DISSIPATION = 1.6mW

R1

17.8kΩ

DAC8043

V

DD RFB

I

V

REF OUT

GND CLK SRI OP295/

OP495

V

O = (4.096V) D

4096

R4

100kΩ

R2

41.2kΩ

R3

5kΩ

+

–

00331-025

Figure 27. A 5 V 12-Bit DAC with 0 V to 4.095 V Output Swing

4 mA TO 20 mA CURRENT-LOOP TRANSMITTER

Figure 28 shows a self-powered 4 mA to 20 mA current-loop transmitter. The entire circuit floats up from the single-supply (12 V to 36 V) return. The supply current carries the signal within the 4 mA to 20 mA range. Thus, the 4 mA establishes the baseline current budget within which the circuit must operate. This circuit consumes only 1.4 mA maximum quiescent current, making 2.6 mA of current available to power additional signal conditioning circuitry or to power a bridge circuit.

4

REF02

GND

100Ω

220Ω

2N1711

1

8 3

2 4

220pF

SPAN ADJ

NULL ADJ

HP

5082-2800

100kΩ

1%

6 2

5V

+

–

+

–

RL

100Ω

12V

TO

36V

4mA

TO

20mA

100Ω

1%

1/2

OP295/

OP495

100kΩ

10-TURN

1.21MΩ

1%

182kΩ

1%

10kΩ

10-TURN VIN

0V + 3V

00331-026

Figure 28. 4 mA to 20 mA Current Loop Transmitter

3 V LOW DROPOUT LINEAR VOLTAGE REGULATOR

Figure 29 shows a simple 3 V voltage regulator design. The regulator can deliver 50 mA load current while allowing a 0.2 V dropout voltage. The OP295/OP495 rail-to-rail output swing drives the MJE350 pass transistor without requiring special drive circuitry. At no load, its output can swing less than the pass transistor's base-emitter voltage, turning the device nearly off. At full load, and at low emitter-collector voltages, the transistor beta tends to decrease. The additional base current is easily handled by the OP295/OP495 output.

The amplifier servos the output to a constant voltage, which feeds a portion of the signal to the error amplifier.

Higher output current, to 100 mA, is achievable at a higher dropout voltage of 3.8 V.

VIN

5V TO 3.2V

MJE 350

43kΩ

AD589

1.235V

3

2

4

1

8

1000pF

I

L < 50mA

V

O

100µF 44.2kΩ

1%

30.9kΩ

1%

1/2

OP295/

OP495

+

–

00331-027

+

+

Figure 29. 3 V Low Dropout Voltage Regulator

Figure 30 shows the regulator’s recovery characteristic when its

output underwent a 20 mA to 50 mA step current change.

10

100

0%

90

20mV 1ms

2V

50mA

20mA

OUTPUT

STEP

CURRENT

CONTROL

WAVEFORM

00331-028

Figure 30. Output Step Load Current Recovery

LOW DROPOUT, 500 mA VOLTAGE REGULATOR

WITH FOLDBACK CURRENT LIMITING

Adding a second amplifier in the regulation loop, as shown in

Figure 31, provides an output current monitor as well as

foldback current limiting protection.

IRF9531

6V G

REF43

2

4

6

2.5V

A2

1 A1

4 2

3

5

6

7

8

1N4148

I

O (NORM) = 0.5A

I

O (MAX) = 1A RSENSE

0.1Ω

S D 1/4W

5V VO

+

–

1/2

OP295/

OP495

1/2

OP295/

OP495

0.01µF

100kΩ

5%

205kΩ

1%

210kΩ

1%

45.3kΩ

1%

45.3kΩ

1%

124kΩ

1%

124kΩ

1%

00331-029

+

–

+

–

Figure 31. Low Dropout, 500 mA Voltage Regulator

with Foldback Current Limiting OP295/OP495

V+

100kΩ

100kΩ

58.7kΩ

R

FREQ OUT

4

1

3 8

2

C

1

RC

F

OSC = < 350Hz @ V+ = 5V

1/2

OP295/

OP495

+

–

+

00331-030

Amplifier A1 provides error amplification for the normal

voltage regulation loop. As long as the output current is less

than 1 A, the output of Amplifier A2 swings to ground, reversebiasing the diode and effectively taking itself out of the circuit.

However, as the output current exceeds 1 A, the voltage that

develops across the 0.1 Ω sense resistor forces the output of

Amplifier A2 to go high, forward-biasing the diode, which in

turn closes the current-limit loop. At this point, the A2’s lower

output resistance dominates the drive to the power MOSFET

transistor, thereby effectively removing the A1 voltage regulation loop from the circuit. Figure 32. Square Wave Oscillator Has Stable Frequency Regardless of

Supply Changes If the output current greater than 1 A persists, the current limit

loop forces a reduction of current to the load, which causes a

corresponding drop in output voltage. As the output voltage

drops, the current-limit threshold also drops fractionally,

resulting in a decreasing output current as the output voltage

decreases, to the limit of less than 0.2 A at 1 V output. This foldback effect reduces the power dissipation considerably during a

short circuit condition, thus making the power supply far more

forgiving in terms of the thermal design requirements. Small

heat sinking on the power MOSFET can be tolerated.

10kΩ

90.9kΩ

V+

10kΩ 100kΩ

20kΩ 20kΩ

V+

SPEAKER

+ + 1/4

OP295/

OP495

1/4

OP295/

OP495

1/4

OP295/

OP495

VIN

2.2µF

–

+

–

+

–

+

00331-031

The rail-to-rail swing of the OP295 exacts higher gate drive to

the power MOSFET, providing a fuller enhancement to the transistor. The regulator exhibits 0.2 V dropout at 500 mA of load

current. At 1 A output, the dropout voltage is typically 5.6 V.

Figure 33. Single-Supply Differential Speaker Driver

HIGH ACCURACY, SINGLE-SUPPLY, LOW POWER

SQUARE WAVE OSCILLATOR COMPARATOR

The OP295/OP495 make accurate open-loop comparators.

With a single 5 V supply, the offset error is less than 300 µV.

Figure 34 shows the response time of the OP295/OP495 when

operating open-loop with 4 mV overdrive. They exhibit a 4 ms

response time at the rising edge and a 1.5 ms response time at the falling edge.

The circuit in Figure 32 is a square wave oscillator (note the positive feedback). The rail-to-rail swing of the OP295/OP495 helps maintain a constant oscillation frequency even if the supply voltage varies considerably. Consider a battery-powered system where the voltages are not regulated and drop over time. The rail-to-rail swing ensures that the noninverting input sees the full V+/2, rather than only a fraction of it.

10

100

0%

90

2V 5ms

1V

OUTPUT

INPUT

(5mV OVERDRIVE

@ OP295 INPUT)

00331-032

The constant frequency comes from the fact that the 58.7 kΩ feedback sets up Schmitt trigger threshold levels that are directly proportional to the supply voltage, as are the RC charge voltage levels. As a result, the RC charge time, and therefore, the frequency, remain constant, independent of supply voltage. The slew rate of the amplifier limits oscillation frequency to a maximum of about

800 Hz at a 5 V supply.

SINGLE-SUPPLY DIFFERENTIAL SPEAKER DRIVER

Connected as a differential speaker driver, the OP295/OP495

can deliver a minimum of 10 mA to the load. With a 600 Ω load,

the OP295/OP495 can swing close to 5 V p-p across the load. Figure 34. Open-Loop Comparator Response Time with 5 mV Overdrive OP295/OP495

Rev. G | Page 14 of 16

OUTLINE DIMENSIONS

COMPLIANT TO JEDEC STANDARDS MS-001

CONTROLLING DIMENSIONS ARE IN INCHES; MILLIMETER DIMENSIONS

(IN PARENTHESES) ARE ROUNDED-OFF INCH EQUIVALENTS FOR

REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN.

CORNER LEADS MAY BE CONFIGURED AS WHOLE OR HALF LEADS. 070606-A

0.022 (0.56)

0.018 (0.46)

0.014 (0.36)

SEATING

PLANE

0.015

(0.38)

MIN

0.210 (5.33)

MAX

0.150 (3.81)

0.130 (3.30)

0.115 (2.92)

0.070 (1.78)

0.060 (1.52)

0.045 (1.14)

8

1

4

5 0.280 (7.11)

0.250 (6.35)

0.240 (6.10)

0.100 (2.54)

BSC

0.400 (10.16)

0.365 (9.27)

0.355 (9.02)

0.060 (1.52)

MAX

0.430 (10.92)

MAX

0.014 (0.36)

0.010 (0.25)

0.008 (0.20)

0.325 (8.26)

0.310 (7.87)

0.300 (7.62)

0.195 (4.95)

0.130 (3.30)

0.115 (2.92)

0.015 (0.38)

GAUGE

PLANE

0.005 (0.13)

MIN

Figure 35. 8-Lead Plastic Dual In-Line Package [PDIP]

(N-8) P Suffix

Dimensions shown in inches and (millimeters)

CONTROLLING DIMENSIONS ARE IN MILLIMETERS; INCH DIMENSIONS

(IN PARENTHESES) ARE ROUNDED-OFF MILLIMETER EQUIVALENTS FOR

REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN.

COMPLIANT TO JEDEC STANDARDS MS-012-AA

012407-A

0.25 (0.0098)

0.17 (0.0067)

1.27 (0.0500)

0.40 (0.0157)

0.50 (0.0196)

0.25 (0.0099) 45°

8°

0°

1.75 (0.0688)

1.35 (0.0532)

SEATING

PLANE

0.25 (0.0098)

0.10 (0.0040)

4

1

8 5

5.00 (0.1968)

4.80 (0.1890)

4.00 (0.1574)

3.80 (0.1497)

1.27 (0.0500)

BSC

6.20 (0.2441)

5.80 (0.2284)

0.51 (0.0201)

0.31 (0.0122)

COPLANARITY

0.10

Figure 36. 8-Lead Standard Small Outline Package [SOIC_N]

Narrow Body (R-8) S Suffix

Dimensions shown in millimeters and (inches) OP295/OP495

Rev. G | Page 15 of 16

COMPLIANT TO JEDEC STANDARDS MS-001

CONTROLLING DIMENSIONS ARE IN INCHES; MILLIMETER DIMENSIONS

(IN PARENTHESES) ARE ROUNDED-OFF INCH EQUIVALENTS FOR

REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN.

CORNER LEADS MAY BE CONFIGURED AS WHOLE OR HALF LEADS. 070606-A

0.022 (0.56)

0.018 (0.46)

0.014 (0.36)

0.150 (3.81)

0.130 (3.30)

0.110 (2.79)

0.070 (1.78)

0.050 (1.27)

0.045 (1.14)

14

1

7

8

0.100 (2.54)

BSC

0.775 (19.69)

0.750 (19.05)

0.735 (18.67)

0.060 (1.52)

MAX

0.430 (10.92)

MAX

0.014 (0.36)

0.010 (0.25)

0.008 (0.20)

0.325 (8.26)

0.310 (7.87)

0.300 (7.62)

0.015 (0.38)

GAUGE

PLANE

0.210 (5.33)

MAX

SEATING

PLANE

0.015

(0.38)

MIN

0.005 (0.13)

MIN

0.280 (7.11)

0.250 (6.35)

0.240 (6.10)

0.195 (4.95)

0.130 (3.30)

0.115 (2.92)

Figure 37. 14-Lead Plastic Dual In-Line Package [PDIP]

(N-14) P Suffix

Dimensions shown in inches and (millimeters)

CONTROLLING DIMENSIONS ARE IN MILLIMETERS; INCH DIMENSIONS

(IN PARENTHESES) ARE ROUNDED-OFF MILLIMETER EQUIVALENTS FOR

REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN.

COMPLIANT TO JEDEC STANDARDS MS-013-AA

032707-B

10.50 (0.4134)

10.10 (0.3976)

0.30 (0.0118)

0.10 (0.0039)

2.65 (0.1043)

2.35 (0.0925)

10.65 (0.4193)

10.00 (0.3937)

7.60 (0.2992)

7.40 (0.2913)

0.75 (0.0295)

0.25 (0.0098)

45°

1.27 (0.0500)

0.40 (0.0157)

COPLANARITY

0.10 0.33 (0.0130)

0.20 (0.0079)

0.51 (0.0201)

0.31 (0.0122)

SEATING

PLANE

8°

0°

16 9

8

1

1.27 (0.0500)

BSC

Figure 38. 16-Lead Standard Small Outline Package [SOIC_W]

Wide Body (RW-16) S Suffix

Dimensions shown in millimeters and (inches) OP295/OP495

Rev. G | Page 16 of 16

ORDERING GUIDE

Model Temperature Range Package Description Package Option

OP295GP −40°C to +125°C 8-Lead PDIP P-Suffix (N-8)

OP295GPZ1

−40°C to +125°C 8-Lead PDIP P-Suffix (N-8)

OP295GS −40°C to +125°C 8-Lead SOIC_N S-Suffix (R-8)

OP295GS-REEL −40°C to +125°C 8-Lead SOIC_N S-Suffix (R-8)

OP295GS-REEL7 −40°C to +125°C 8-Lead SOIC_N S-Suffix (R-8)

OP295GSZ1

−40°C to +125°C 8-Lead SOIC_N S-Suffix (R-8)

OP295GSZ-REEL1

−40°C to +125°C 8-Lead SOIC_N S-Suffix (R-8)

OP295GSZ-REEL71

−40°C to +125°C 8-Lead SOIC_N S-Suffix (R-8)

OP495GP −40°C to +125°C 14-Lead PDIP P-Suffix (N-14)

OP495GPZ1

−40°C to +125°C 14-Lead PDIP P-Suffix (N-14)

OP495GS −40°C to +125°C 16-Lead SOIC_W S-Suffix (RW-16)

OP495GS-REEL −40°C to +125°C 16-Lead SOIC_W S-Suffix (RW-16)

OP495GSZ1

−40°C to +125°C 16-Lead SOIC_W S-Suffix (RW-16)

OP495GSZ-REEL1

−40°C to +125°C 16-Lead SOIC_W S-Suffix (RW-16)

1

Z = RoHS Compliant Part.

D00331-0-8/09(G)

END