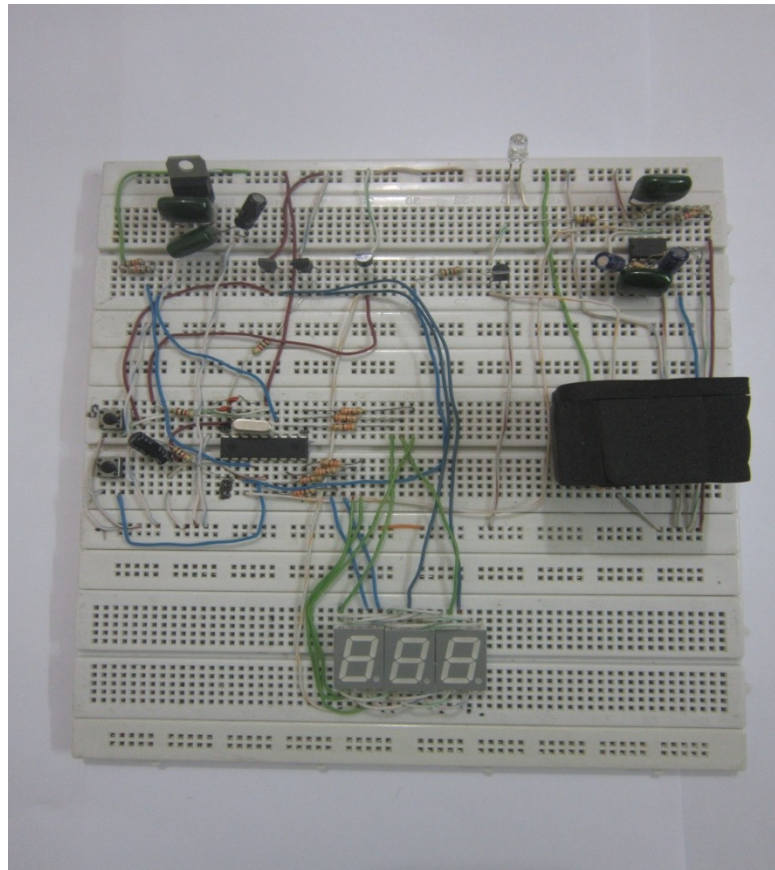


# Heart Rate Measurement Project



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**Abstract:** This paper describes the design of a simple, low-cost microcontroller based heart rate measuring device with three digit seven segment display. Heart rate of the subject is measured from the finger using optical sensors to detect the flow of blood through the finger. The main analog signal received from the human body gets captured with an instrumentation amplifier MCP602. Then the signal is filtered with another Op-Amp. The pulses are counted by a microcontroller and the output of the circuit is displayed on the seven segment clearly. This project design provides fastness and safety. Moreover, the installation of this device is very easy.

**Keywords:** BPM (Beats Per Minute), Microcontroller, Pulse, Multiplexing, Opamp

## Introduction

Heart rate measurement is one of the very important parameters of the human cardiovascular system. The heart rate of a healthy adult at rest is around 72 beats per minute (bpm). Athletes normally have lower heart rates than less active people. Babies have a much higher heart rate at around 120 bpm, while older children have heart rates at around 90 bpm. The heart rate rises gradually during exercises and returns slowly to the rest value after exercise. The rate when the pulse returns to normal is an indication of the fitness of the person. Lower than normal heart rates are usually an indication of a condition known as bradycardia, while higher than normal heart rates are known as tachycardia.

Heart rate is simply and traditionally measured by placing the thumb over the subject's arterial pulsation, and feeling, timing and counting the pulses usually in a 30 second period. Heart rate (bpm) of the subject is then found by multiplying the obtained number by 2. This method although simple, is not accurate and can give errors when the rate is high.

This project describes a technique of measuring the heart rate through a fingertip using a PIC microcontroller. While the heart is beating, it is actually pumping blood throughout the body, and that makes the blood volume inside the finger artery to change too. This fluctuation of blood can be detected through an optical sensing mechanism placed around the fingertip. The signal can be amplified further for the microcontroller to count the rate of fluctuation, which is actually the heart rate.

The device has the advantage that it is microcontroller based and thus can be programmed to display various quantities, such as the average, maximum and minimum rates over a period of time and so on. Another advantage of such a design is that it can be expanded and can easily be connected to a recording device or a PC to collect and analyze the data for over a period of time.

## Equipments

Component Details	Specification	Quantity
Bread board		3 unit
Capacitance	0.1uF 1uF 10uF 22pF 100nF	1 Piece 2 Piece 1 Piece 2 Piece 4 Piece
Connecting wires		As per requirement
Crystal	4.0MHz	1 Piece
DC Adapter	9V Output	1 unit
IR Diode		1 Piece
Led light	Red colour	1 piece
Multimeter		1 unit
OPAMP	MCP602	1 Piece
Photo Diode		1 Piece
PIC Microcontroller	PIC16F628A	1 Piece
Regulator IC	LM7805	1 Piece
Resistor	150ohm 330ohm 470ohm 1k 6.8k 10k 33k 68k 680k	1 Piece 7 Piece 1 Piece 3 Piece 2 Piece 2 Piece 1 Piece 2 Piece 2 Piece
7 Segment Display	Common anode, single digit	3 Piece
Tact Switch		2 Piece
Transistor	BC557 BC547	3 Piece 1 Piece

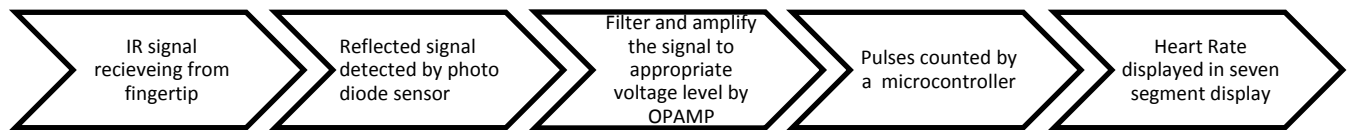


Fig 1 : Step By Step Process of Heart Rate Measurement

## Component Details

### Microcontroller

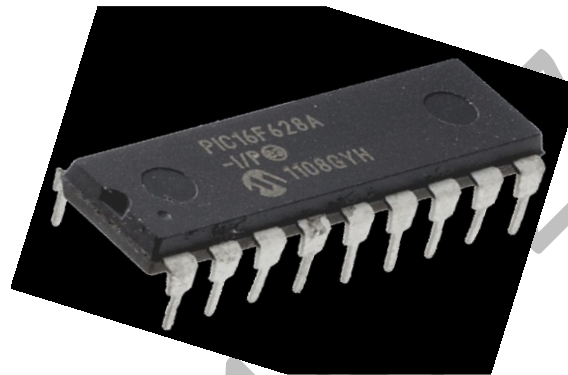
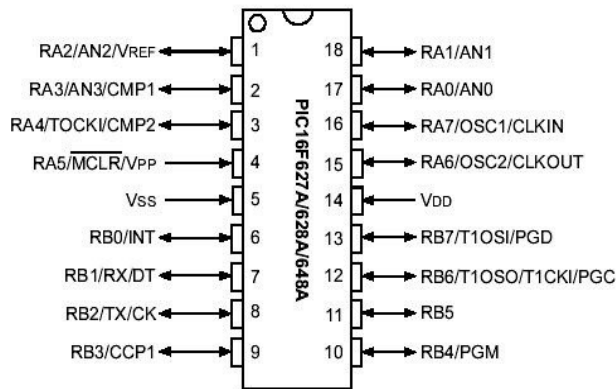


Fig 2 : Microcontroller

A microcontroller (sometimes abbreviated  $\mu\text{C}$ ,  $\text{uC}$  or  $\text{MCU}$ ) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. It is a simplified CPU, plus some amount of RAM, plus some amount of (re)programmable ROM, plus some I/O ports (including some analog I/O ports), and all of this in a single small chip.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, and toys. These are also used at many electronic devices, including microwave ovens and washing machines. They are simple and useful enough to be used in many DIY (do it yourself) projects. They usually can run at a clock rate of a few MHz.



Pin Configuration (PIC16F628A)

Pin Number	Description
1	RA2/AN2/Vref - Port A
2	RA3/AN3/CMP1 - Port A
3	RA4/TOCK1/CMP2 - Port A
4	RA5/MCLR/THV - Port A
5	Vss - Ground
6	RB0/INT - Port B
7	RB1/RX/DT - Port B
8	RB2/TX/CK - Port B
9	RB3/CCP1 - Port B
10	RB4/PGM - Port B
11	RB5 - Port B
12	RB6/T1OSO/T1CK1 - Port B
13	RB7/T1OS1 - Port B
14	Vdd - Positive Power Supply
15	RA6/OSC2/CLKOUT - Port A
16	RA7/OSC1/CLKIN - Port A
17	RA0/AN0 - Port A
18	RA1/AN1 - Port A

Fig 3: Pin Configuration And Description

### Operational Amplifier

Instrumentation Amplifier is a kind of differential amplifier which consists of input buffer that omits the need of input impedance matching. It makes the IC suitable for different kinds of measurement. This amplifier has a very low DC offset, low drift, low noise, high open-loop gain and very high input impedance. This amplifier is used where great accuracy and stability is required for both short and long term. The very initial step of this project is to take analog signal from human body. We have used an instrumentation amplifier to receive this signal. This IC is called 'MCP602'. This IC gives additional fixed amplification to the heartbeat signals. The A/D conversion stage of the device is controlled by a microcontroller IC named PIC16F628A. It operates at a frequency range of 4MHz.

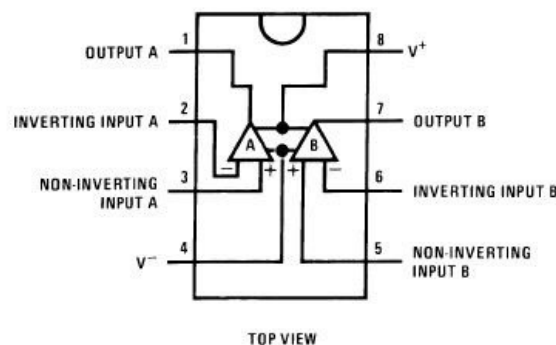


Fig 4: Mcp602 Amplifier

## Crystal Oscillator

A crystal oscillator is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a very precise frequency. This frequency is commonly used to keep track of time (as in quartz wristwatches), to provide a stable clock for digital integrated circuits, and to stabilize frequencies for radio transmitters and receivers. The most common type of piezoelectric resonator used is the quartz crystal, so oscillator circuits designed around them became known as "crystal oscillators." Quartz crystals are manufactured for frequencies from a few tens of kilohertz to tens of megahertz. More than two billion ( $2 \times 10^9$ ) crystals are manufactured annually. Quartz crystals are also found inside test and measurement equipment, such as counters, signal generators, and oscilloscopes. It features High Accuracy, Wide Temperature Rang.



Fig 5: A miniature 4 MHz crystal

## Application

### Voltage Regulation

A regulated +5V power supply is derived from an external 9V DC adapter using an LM7805 regulator IC. 7805 gives fixed 5V DC voltage if input voltage is in (7.5V, 20V).

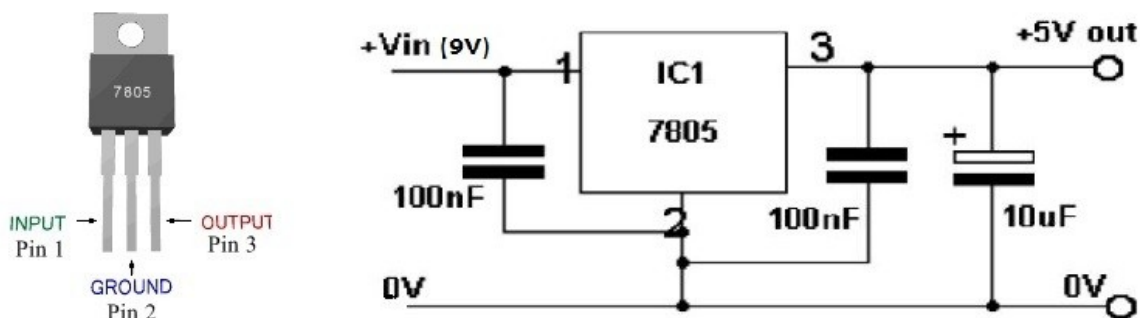


Fig 6: 7805 Regulator IC And It's Connection



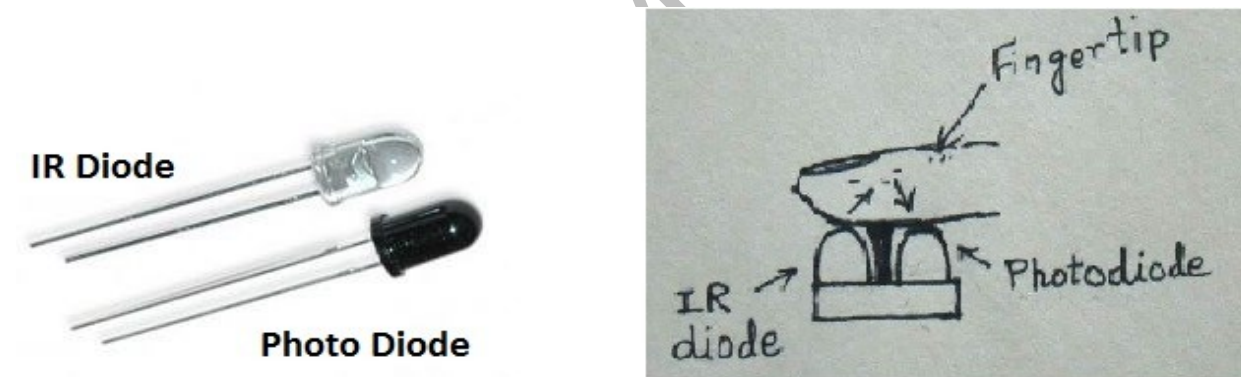
The above diagram shows how to use 7805 voltage regulator. In this circuit coupling capacitors are used for good regulation otherwise the noise in the output voltage will be high.

## Sensor

In this project there are two types of diodes. They are-

1. Infrared light-emitting-diode (IR LED) TX
2. Photo diode RX

IR Sensors (IR stands for Infra-Red detect infra red radiations coming from a body or a transmitter. IR sensor could be a containing a single receiver (in case where a body is a source of IR radiations) or it could be a pair of Transmitter and Receiver .The transmitter could be detected by a simple circuit by connecting a  $330\Omega$  resistance in series with the transmitter and applying a power source of 5V to it. Then one could view the transmitter with any of thermographic camera/lens, one could view a bright light (mostly blue in color) coming out of the transmitter that is not visible from naked eyes. So, this way we can say that the IR diode is working.

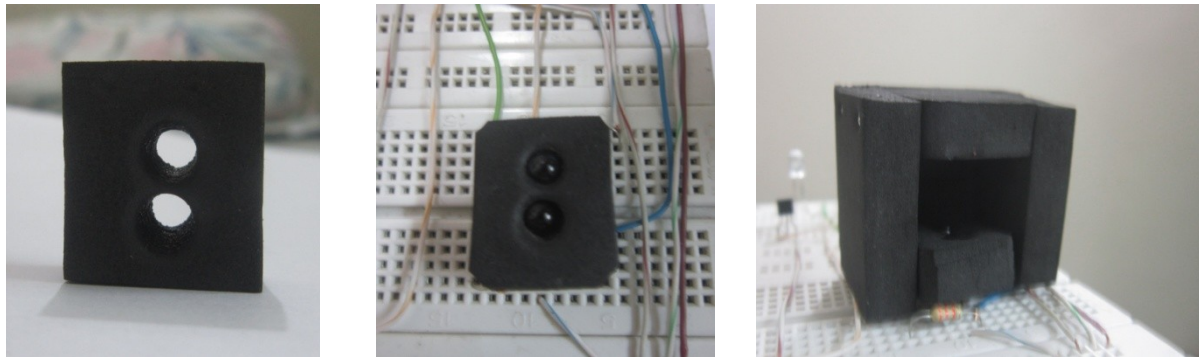


**Fig3: IR Diode And Photo Diode**

This two diodes are placed side by side and the fingertip is placed over the sensor assembly. The IR LED transmits an infrared light into the fingertip, a part of which is reflected back from the blood inside the finger arteries. The photo diode senses the portion of the light that is reflected back. The intensity of reflected light depends upon the blood volume inside the fingertip. So, every time the heart beats the amount of reflected infrared light changes, which can be detected by the photo diode. With a high gain amplifier, this little alteration in the amplitude of the reflected light can be converted into a pulse. To work properly this two diodes need proper environment so that light from outside could not hamper its work. The IR



transmitting diode and the photo diode are placed closely but any direct crosstalk between the two are avoided. Surrounding the sensor with an opaque material makes the sensor system more robust to changing ambient light condition.



## Signal Conditioning

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.

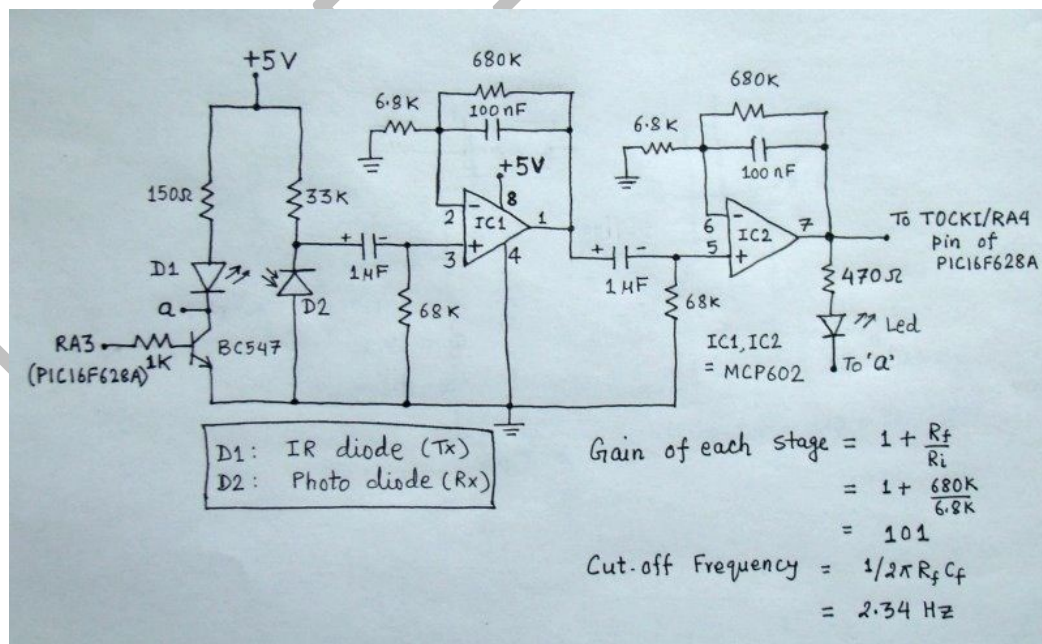


Fig 7: signal conditioning circuit

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 heart beat is detected. The output from the signal conditioner goes to the T0CKI input of PIC16F628A. 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. So we've done practical test circuit to find the appropriate value of the series resistor for the IR diode we used.

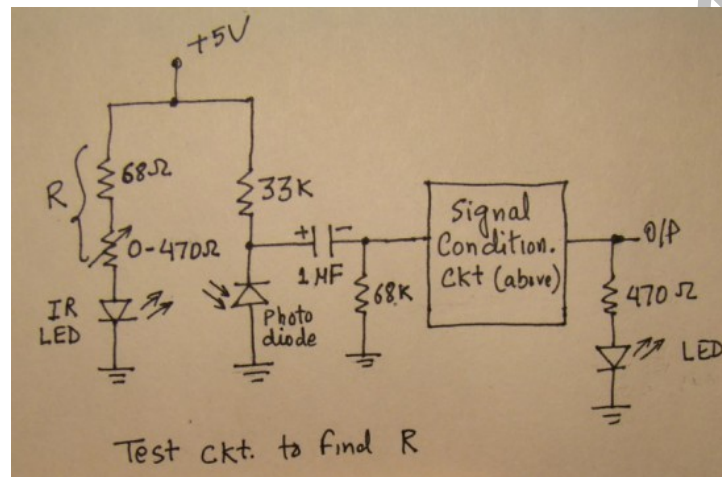


Fig 8: Test Circuit

First we used a potentiometer in series with the IR diode. Placing a fingertip over the sensor assembly, slowly the potentiometer was varied till the output LED blinking with heartbeat was found. Then the equivalent resistance was measured the potentiometer can be kept in the circuit so that we can always adjust it when needed. Fingertip should be kept very still over the sensor while testing. Once we've seen the pulses at the output of the signal conditioning circuit, we've fed them to a microcontroller to count and display.

## Display Unit

A seven segment interfaced with PIC uses almost an entire port (minimum 7 pins) to display a value. But a real time application usually requires at least 3-4 seven segments. In such a case it is not advisable to use a port of the controller for each seven segment. In these cases, multiplexing technique is used to work with more than one seven segment. The theory behind the multiplexing technique is simple. All the similar segments of multiple LED displays are connected together and driven through a single I/O pin. In the upper circuit, the seven

segments are connected to PORTB through current limiting resistors  $R_s$ . A particular segment is active when the corresponding PORTB pin is low. However, it will not glow until its anode is connected to  $V_{cc}$ . The anodes of the four LED displays are not directly connected to  $V_{cc}$ . Instead, 3 PNP transistors are used as switches to connect or disconnect the anode terminals from  $V_{cc}$ . When the base of the PNP transistor is low, the transistor conducts and corresponding digit's common anode is connected to  $V_{cc}$ . Therefore, the transistor selects which displays is active. The conduction of the transistors are controlled by RA0 through RA2

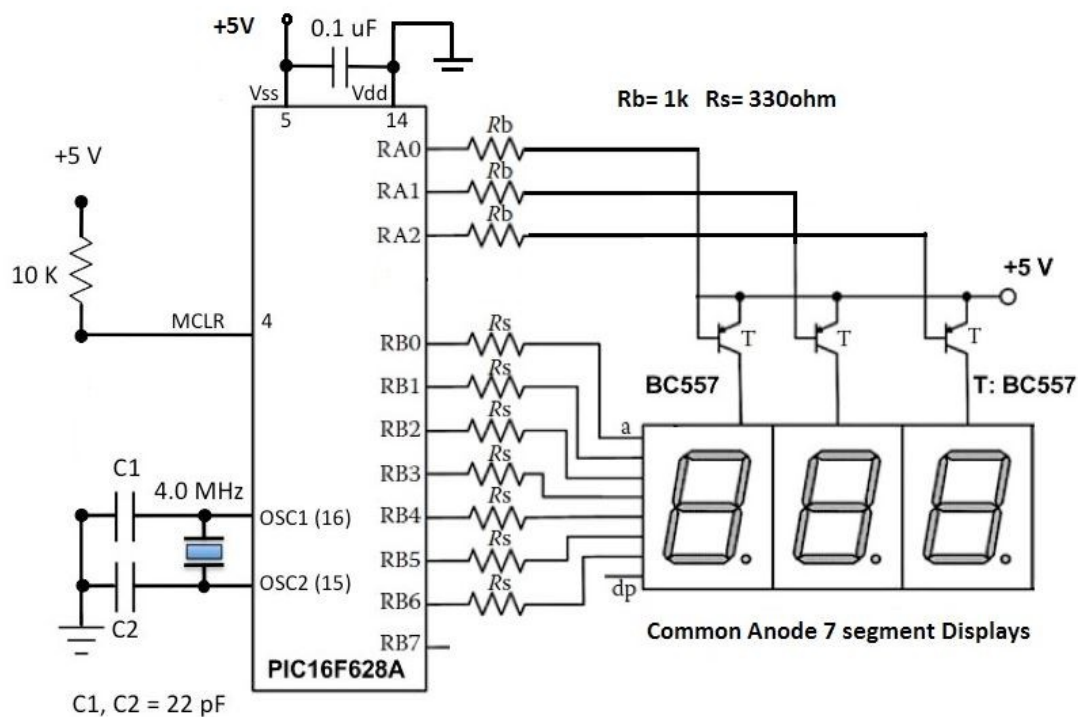


Fig 9: Multiplexing Technique

pins of PORTA. 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. In order to display all 3 digits, each seven-segment display is activated sequentially using an appropriate refresh frequency so that it will appear that all the them are turned on at the same time.

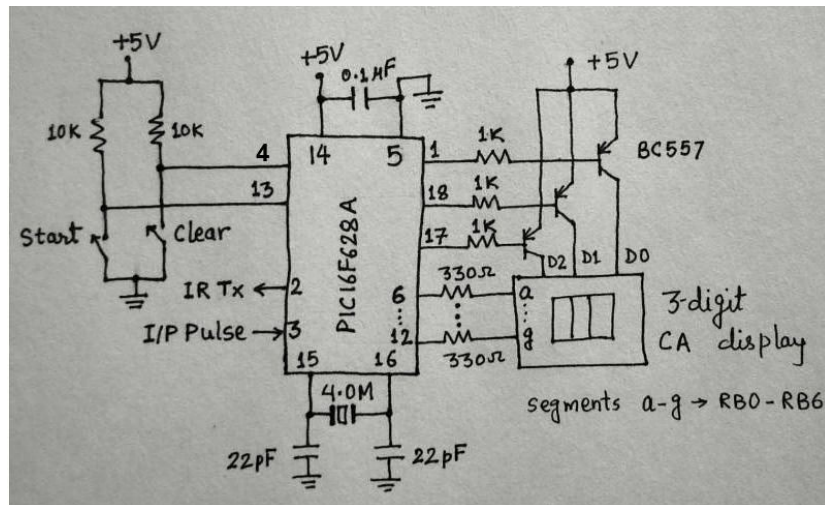


Fig 10: Microcontroller and Display Circuit

The display unit comprises of a 3-digit, common anode, seven segment module that is driven using multiplexing technique. 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. The IR transmission is controlled through RA3 pin of PIC16F628A.

## Working Procedure

Voltage regulators produce fixed DC output voltage from variable DC. In microcontroller a fixed frequency have to give. Here we are using a crystal oscillator of 4.0MHz to give this frequency. Two capacitors are with this crystal which are for crystal to start oscillating. First fingertip is placed in the sensor. Then start button is pressed to start the microcontroller. This microcontroller then turns on the npn transistor (BC547). Then the pulse will go through the IR diode and then photo diode. Then the signal will go from the capacitor of 1µF which will block the DC noise from the signal. The reflected IR signal detected by the photo diode is fed to a signal conditioning circuit that filters the unwanted signals and boost the desired pulse signal. The IR LED (D1) and the photo diode (D2) along with the signal conditioning circuit made of two stage operational amplifiers configured as active low pass filters. The cut-off frequencies of both the filters are set to about 2.5 Hz, and so it can measure the pulse rate up to  $2.5 \times 60 = 150$  bpm. The gain of each filter is about 100, which gives the total 2-stage amplification of 10000. This is good enough to convert the weak pulsating signal into a TTL pulse. At the output is connected a LED that will blink with heart beat. The cathode of LED gets the ground path through the collector of BC547 transistor. In order to save the battery life, the transistor is

turned on for 15 seconds by PIC16F628A microcontroller while the measurement is going on. The number of pulses counted within this interval is multiplied by 4 to get actual beats per minutes (bpm).

Now this signal will go to the microcontroller through RA4. Then the program will run and count the heart beat for 15 sec and multiply it with 4 and send it to the display. Here we use 7 segment display. For this we have to multiplex D1, D2, D3. This display show the heart beat per min.

## Code For Microcontroller

```

/*
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
}
```

## Output

The use of this device is very simple. We have to turn the power on and we will see all zeros on display for few seconds. We have to wait till the display goes off. Now place forefinger tip on the sensor assembly, and press the start button. We will see the LED blinking with heart beats and after 15 sec, the result will be displayed. This implementation of a heart monitor involves low cost amplifier and filter components coupled with a microcontroller and seven segment display.

## TROUBLESHOOT

We faced some difficulties for making this project. Now we will discuss about how we have troubleshot these problems.

### Constant 5v Supply:

To work the whole project properly, a constant dc 5v supply is needed. So using the batteries may not be able to do so, as it will decrease with time. So we've used dc adapter (9v) and regulator IC (7805) for constant 5v supply.

### Microcontroller program:

Microcontroller (PIC16F628A) is one of the important part of our project as it count the pulses and the output is shown on the display. So the program of the microcontroller must be burnt accurately otherwise it will not work.



### Transistor Switching:

We've used npn (BC547) and pnp (BC557) transistors . First we've given the connection of emitter , collector, base according to the datasheet and it didn't work because the pin arrangement can be different because of different companies. So we've checked the pin arrangement with multi meter and also checked if it's working properly as switch.

### Multiplexing:

For this project we've used common anode, seven segment single digit displays. The multiplexing must be accurate and the connection with microcontroller must be accurate otherwise the corresponding LED's will not glow.

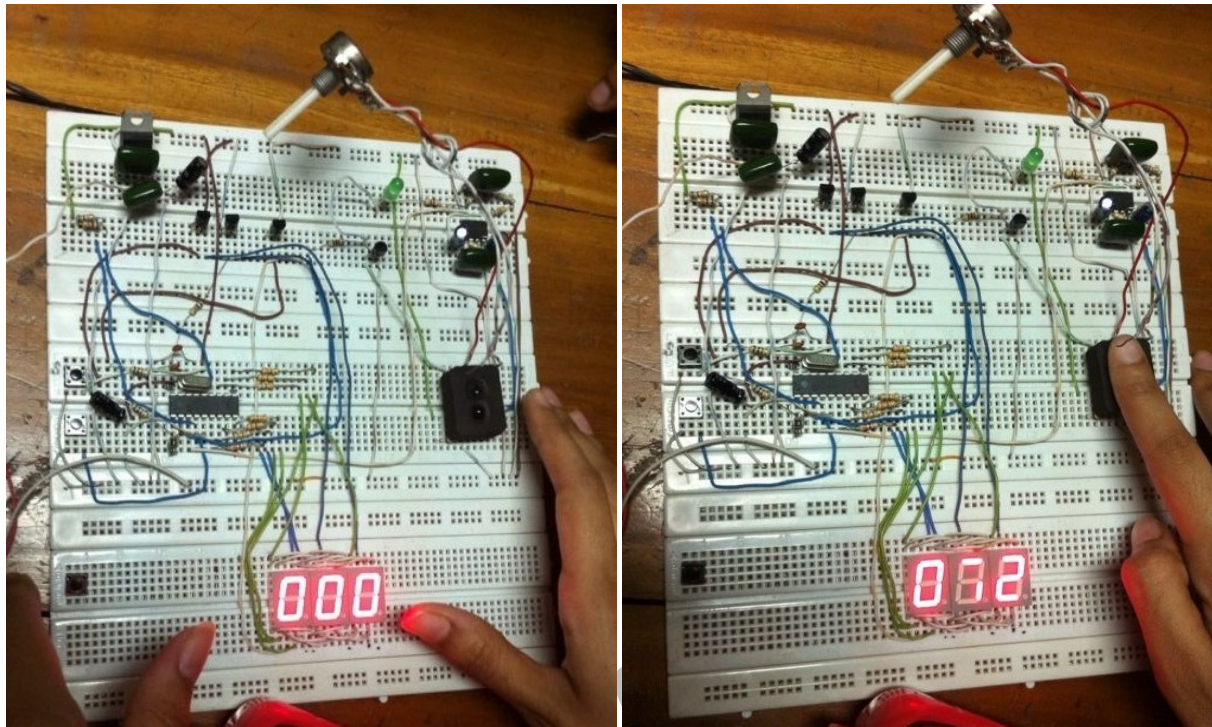
### Pulse Detection:

The harder part of this project is pulse detection. 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. So we've done practical test circuit to find the appropriate value of the series resistor for the IR diode we used. First we used a potentiometer in series with the IR diode. Placing a fingertip over the sensor assembly, slowly the potentiometer was varied till the output LED blinking with heartbeat was found. Then the equivalent resistance was measured the potentiometer can be kept in the circuit so that we can always adjust it when needed. Fingertip should be kept very still over the sensor while testing. Once we've seen the pulses at the output of the signal conditioning circuit (using oscilloscope), we've fed them to a microcontroller to count and display.

### Future Work

1. Sound can be added to the device so that a sound is output each time a pulse is received.
2. The maximum and minimum heart rates over a period of time can be displayed .
3. Serial output can be attached to the device so that the heart rates can be sent to a PC for further online or offline analysis.

## Project Images



## Conclusion

In this paper, the design and development of a low-cost microcontroller based device for measuring the heart pulse rate has been described. The device has the advantage that it can be used by non-professional people at home to measure the heart rate easily and safely. The device is ergonomic, portable, durable, and cost effective. The device is efficient and easy to use. This device could be used in clinical and nonclinical environments. It can also be easily used by individual users, e.g. athletes during sporting activities.

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