



UNIVERSIDAD JESUITA
DE GUADALAJARA

ITESO

1-5-2015

Photoplethysmography device based on Galileo

Video available: <https://www.dropbox.com/s/281f8wgovkjjrzc/Photoplethysmograph.mp4?dl=0>

Electronic Circuits Project



Team members:

Name:

Erick Ortega Prudencio
Patricio Alejandro Gómez García
(Second semester, **Electronics Engineering**)

e-mail:

ie698825@iteso.mx
ie697875@iteso.mx

Teacher:

M.C. José Bernardo Cotero Ochoa

bcotero@iteso.mx

ITESO, Coordinator of Electronics Engineering program:

Ph. D. Omar Longoria-Gandara
<http://carreras.iteso.mx>

olongoria@iteso.mx

Index

Objective.	2
Project planning.....	5
Project Design	6
PCB design.....	7
Software design.	7
Practical Development.	10
Protoboard Test.	10
PCB manufacturing and implementation on Intel’s Galileo.	11
Conclusions and result analysis.....	18
References	18

Objective.

The objective of this project is to build a Photoplethysmography device¹ (PPG) [1] in order to be able to register the human cardiac activity. The project use an Intel Galileo board and the information recovered by the *PPG* will be transmitted to a computer for a further analysis.



Figure 1- Commercial pulse oximeter. Source: Vekiel (2015) [2]

A commercial *PPG* is shown in Figure 1. This device gets heart pulse information and oxygen levels of a person. The block diagram of the system is described in Figure 2. It can be observed that the analog circuit is in charge of receiving the signal from the sensor, then it sends the information to the Galileo board that process the signal coming from the sensor and translate it into a digital signal that will be transmitted to the computer for plotting and further analysis of the data.

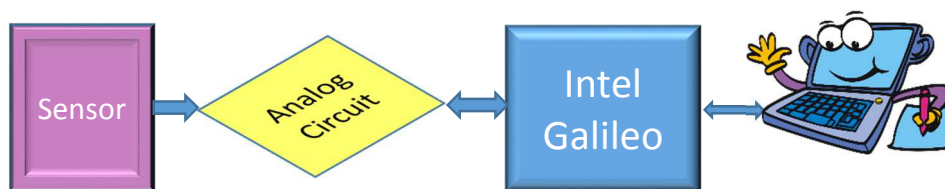


Figure 2- Block diagram of the PPG. Source: Departamento de Electrónica, Sistemas e Informática (2015.)

Figure 3 shows the schematic diagram of the PPG circuit that will be implemented in this project and the list of components that are needed to complete this project is shown on Table I.

¹ A Photo-plethysmograph device measures the blood flow and interprets the pulsations of the hearth.

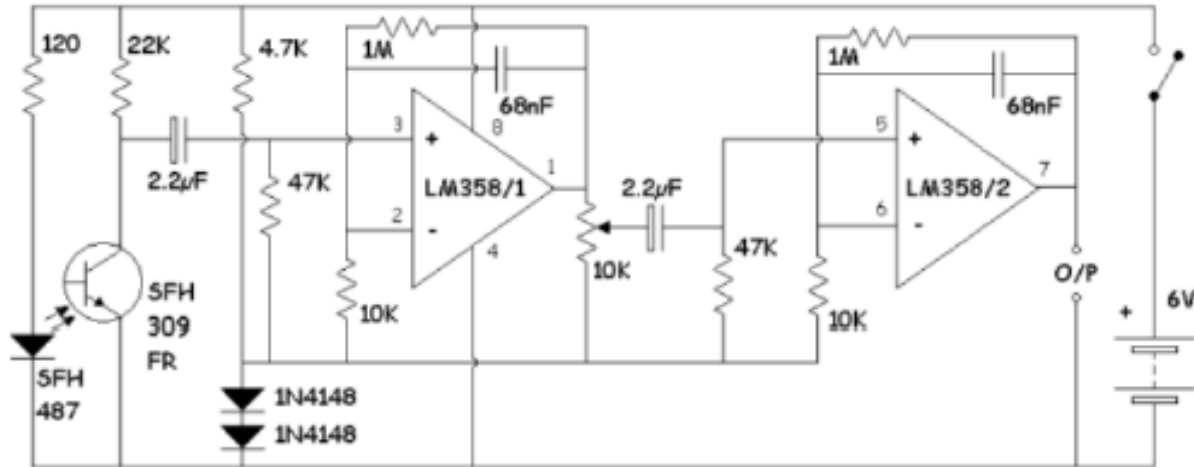


Figure 3- Schematic diagram of the PPG circuit. Source: Departamento de Electrónica, Sistemas e Informática (2015)

Table I- List of electronic components for the PPG circuit.

Quantity	Name	Code / value
1	Operational Amplifier	LM358
2	Signal diodes	1N4148
2	Electrolytic capacitors	2.2 uf
2	Polyester capacitors	68 nf
1	Photodetector	SFH309FR
1	Infrared led	SFH487
9	Resistors	¼ watt
1	Trim pot	10 k

An operational amplifier (OpAmp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and a single-ended output. In this configuration, an OpAmp produces an output voltage that is typically hundreds of thousands of times larger than the voltage difference between its input terminals. According to its data-sheet features given by Motorola, the LM358 has low power drain, a common mode input voltage range extending to ground/VEE and single supply or split supply operation. This OpAmp, can operate at supply voltages as low as 3.0V or as high as 32V.

The two signal diodes (1N4148), in this circuit have the function of quickly dissipating any unwanted transients. This is done in order to protect input/output parallel ports against electrostatic discharge, in digital or computer circuits, by connecting the 2 signal diodes in series. The data-sheet of this component given by Microsemi shows that the application of this component is used in general purpose applications where a controlled forward characteristics and fast switching speed are important.

The Trim pot (Trimming Potentiometer) of 10kΩ, is a small potentiometer used for adjustment, tuning and calibration of the circuit, they are meant to be adjusted when it is installed but never adjusted by the device's user. The function of the Trim pot in the PPG is to make an adequate plot of the cardiac activity; this is done by calibrating how much current will flow through the potentiometer (by changing its resistance), and therefore, plotting an accurate graph of the cardiac activity of the user.

The Photodetector (SFH309FR), is a lighting sensor, it's a photo-transistor and will be used to detect the light emitted by the infrared LED.

The SFH487 is a LED (Light-emitting diode) that emits light in the infrared wavelength. The emitting light won't be visible, but will be detected by the photodetector.

The circuit is complemented with an Intel Galileo board that receives the analog information of the voltage and converts it into a digital signal that will be sent to a computer for plotting and interpreting the cardiac activity.

Intel Galileo [3] is a microcontroller board based on the Intel Quark SoC X1000 application processor that is a 32-bit Intel Pentium-class system on a chip. It has 14 digital inputs/outputs pins, 6 analog inputs, an output pin of 5V and another of 3.3V. The recommended input voltage is 5V. Galileo has a number of facilities for communicating with a computer, another Arduino or others microcontrollers. The options can be UART TTL (5V/3.3V) serial communication, USB client, USB host, PCI Express, Ethernet RJ45 Connector, microSD, TWI/I2C* and SPI.

Project planning.

The original planning of the project is shown in the following table. As it can be seen, the total duration of the project is about 6 weeks long. It can be observed in Table II that the report documentation has the longest duration if it is compared with the other processes of the project. This is because the report has to be started at the beginning of the project and needs to be updated during the implementation in order to register the processes, the changes and the evolution of the project.

Table II- Project planning.

	Abril																														Mayo																		
Actividad	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19					
Arm the circuit on the protoboard																																																	
Design the PCB on computer																																																	
Manufacture the PCB																																																	
Weld and assemble the components on the PCB																																																	
Make the communication program between the computer and the Galileo board																																																	
Project report																																																	
Project deadline																																																	

Project Design

The circuit that is going to be constructed is a photo-plethysmography device which. As it can be seen on Figure 4, this device uses an infrared LED that emits light which passes through the finger of the user and is detected by the photodetector, this means that as the blood flows, this pair of components monitor the flow of the blood and interpret it as a voltage which is sent to the amplifier in order to filter the information (block the noise) and amplify the signal, so we can measure the cardiac activity.

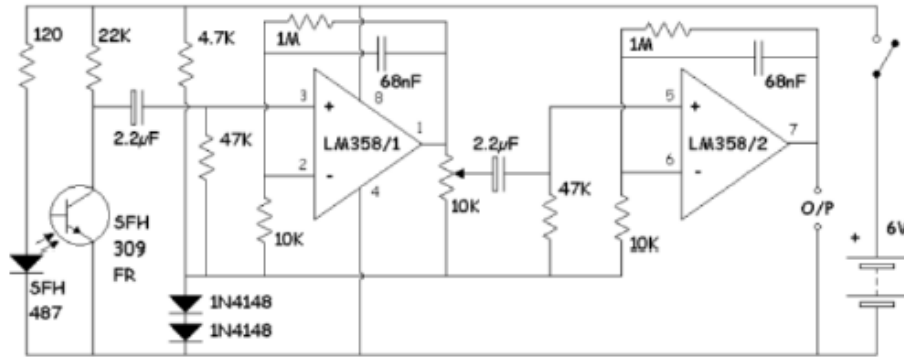


Figure 2- Schematic diagram of the PPG. Obtained from Pico (2015) [4].

Based on the circuit of Figure 4, and taking into account the value of the electronic components of it, a schematic circuit was made on the free-ware version of the PC software Eagle (version 7.3) (Figure 5). All the schematic components have their own value written. This is something very helpful at the moment of welding the components on the Printed Circuit Board (PCB) because is easier to verify the correct location of a component.

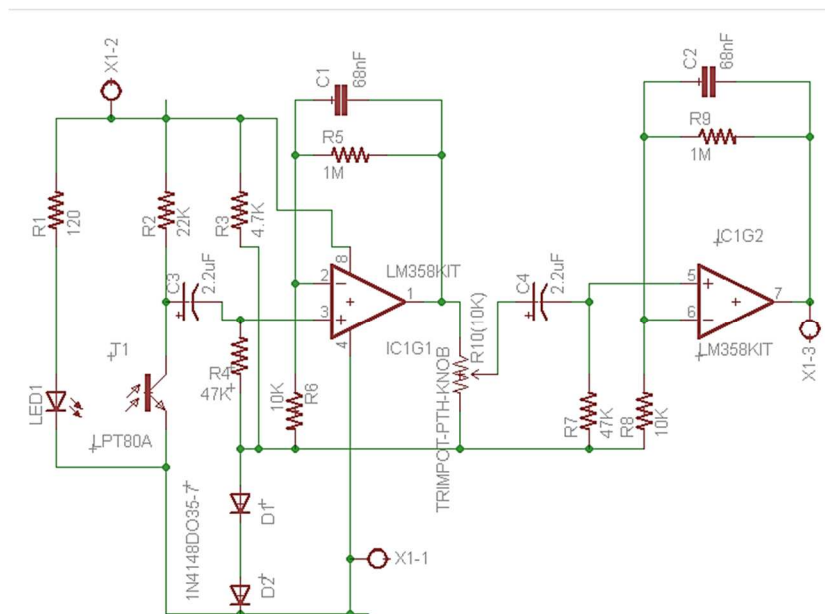


Figure 3- Schematic diagram of the PPG made on Eagle.

PCB design.

Once the schematic diagram was made, the following points were taken into account before designing the PCB:

- Maximum size of the board: 5cm x 5cm.
- The LED and photodetector, must be in front of each other
- Minimum width of the routes of the circuit: 16 millimeters.
- Vcc, ground and the output need to be easy to identify.
- The PCB needs at least three holes for support (for physical implementation).

The board designed is shown on Figure 6.

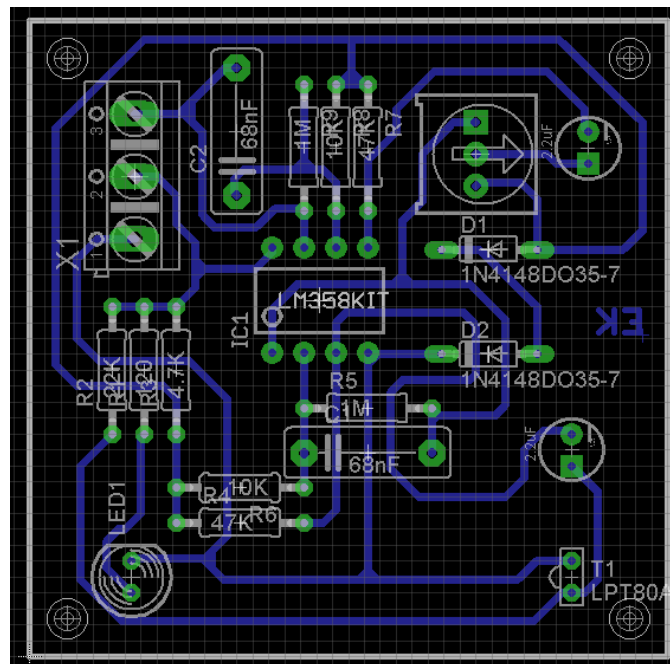


Figure 4- Board diagram of the PPG circuit. Designed by Erick Ortega.

Software design.

Intel's Galileo is in charge of taking the data from the circuit and transmitting it to the computer. Because of that, a code was developed just send the data obtained via the serial port.

This code (shown below) reads the voltage of the output of the circuit and transforms it into a digital signal using the ADC (analogic digital converter) of the Galileo. After the Galileo converts the analogic signal (the voltage obtained from the output of the circuit) into a digital signal, it sends it to the computer through serial communication.

Galileo code:

```
void setup() {
  // initialize the serial communication:
  Serial.begin(115200); //115200
}

void loop() {
  // send the value of analog input 0:
  Serial.println(analogRead(A0));
  // wait a bit for the analog-to-digital converter
  // to stabilize after the last reading:
  delay(28); //28 ms
}
```

The following MATLAB code was developed in order to obtain the data from the serial port and graph the values obtained on the computer in real time. The first thing MATLAB does is open a connection with the serial port and set the baud rate of it. In other words, the first thing the program does is that it configures the serial port. Once the serial port is configured the program prepares the figure where the signal obtained from Intel's Galileo is going to be plotted.

In order to be able to graph the values obtained from the Galileo (and in order to calculate the user's BPM, also) the program creates a vector with the purpose to save all data received from the serial port. Each time the program receives new data it updates the plot and also the BPM.

MATLAB code:

```
% configure serial port-----
%delete previous
delete(instrfind({'Port'},{'COM6'}));
%Create serial object
s = serial('COM6','BaudRate',115200,'Terminator','CR/LF'); %9600 115200
warning('off','MATLAB:serial:fscanf:unsuccessfulRead');
%open the port
fopen(s);

%Graph serial data and obtain Beats per minute -----
%Create a figure
f = figure('Name','Captura');
%for loop that repeats the process the process n times.
for ii=1:2
  %measurment parameters-----
  tmax = 20; % maximum capture time
  rate = 32; % rate of bits taken per second
  contador = 0; % counter used for updating the bpm's
  frecfin = 0; % frequency value that is going to be display.
  %Prepare the figure with an x abscis from 0 to tmax and y from 0 to 5.1
  delete(f); % Delete the information of the figure
  a = axes('XLim',[0 tmax], 'YLim', [0 5.1]); % axes of the figure
  ll = line(nan,nan,'Color','r','LineWidth',2);
  xlabel('Tiempo (s)','FontSize',16);
  ylabel('Voltaje (V)','FontSize',16);
  title(sprintf('Frecuencia Cardiaca:%d lat/min',frecfin))
end
```

```

grid on
hold on
%inicializar (creamos un vector lleno de ceros de tamaño 1 fila,
% tmax*rate columnas, donde se almacenaran los datos recibidos.
% initialize a vector of lenght tmax*rate with zeros.
v1=zeros(1,tmax*rate);
i=1;% Variable to move through the vector
t=0;% variable to measure time between tic and toc
% execute cronometed loop
tic
while t<=tmax
    t = toc;
    % read serial port
    a = fscanf(s, '%d,%d');
    % Convert value readen to voltage
    v1(i) = a(1)*5/1023;
    % Plot in the figure the vector v against the vector x
    % The vector x has a lenght from i, and incrementes by i/rate
    x = linspace(0,i/rate,i);%vector of the x axe that measures time
    xlim([t-5 t]);
    plot(11,'YData',v1(1:i),'XData',x);
    % Update the frequency value BPM -----
    if contador == 5

[picol,loc1]=findpeaks(v1,'minpeakdistance',13,'minpeakheight',2.5);%3.3
        frec=length(picol)*60/t;%Se multiplica por seis para saber
cuantos latidos son por cada minuto (10 segundos * 6)
        frecfin=round(frec);
        title(sprintf('Frecuencia Cardiaca:%d lat/min',frecfin))
        contador = 0;

    end
    contador = contador +1;
    drawnow %update figure
    % next value of the vector x and v1 (i++)
    i= i+1;
end
ii = ii+1;
end
% print cronometer result. It helps to improve the system calibration.
clc;
fprintf('%g s de captura a %g cap/s \n',t,i/t);
pause();
% close serial port-----
fclose(s);
delete(s);
clear s;

```

Practical Development.

Protoboard Test.

Once the coding was finished, the circuit from was implemented on a Protoboard (before manufacturing the PCB), taking into account the electronic components of the schematic design made on the computer.

Figure 7 shows the circuit assembled on the protoboard. As shown in Figure 8, the infrared LED and the photodetector were put face to face so the user's finger could fit between them.

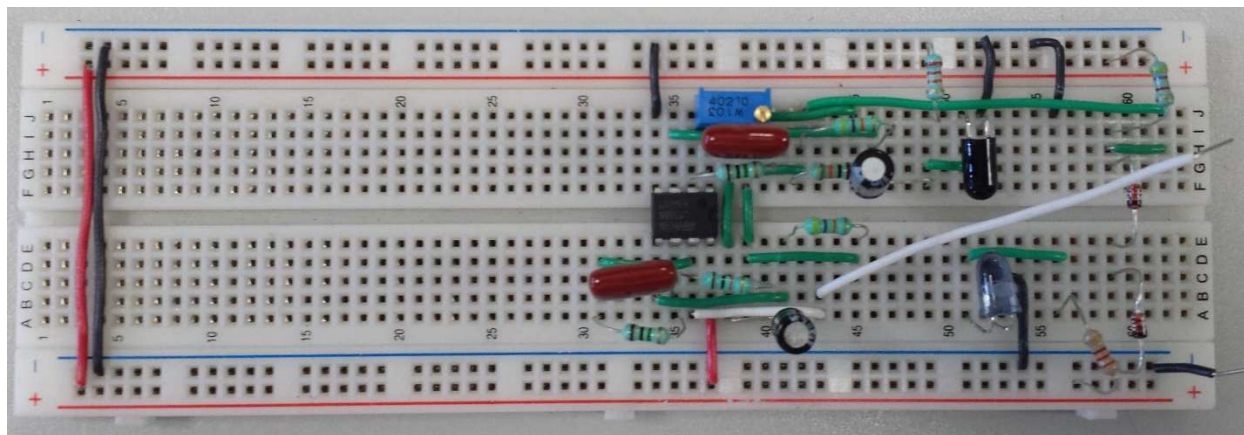


Figure 5- PPG circuit assembled on protoboard.

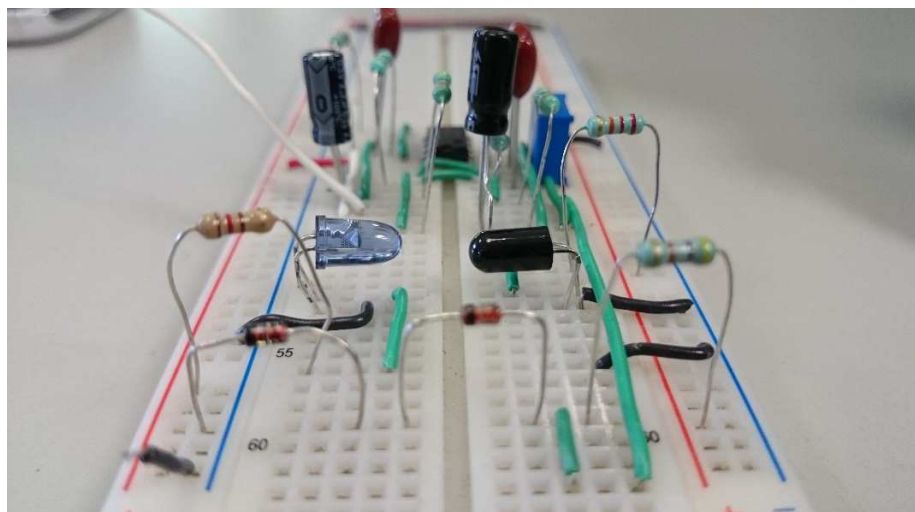
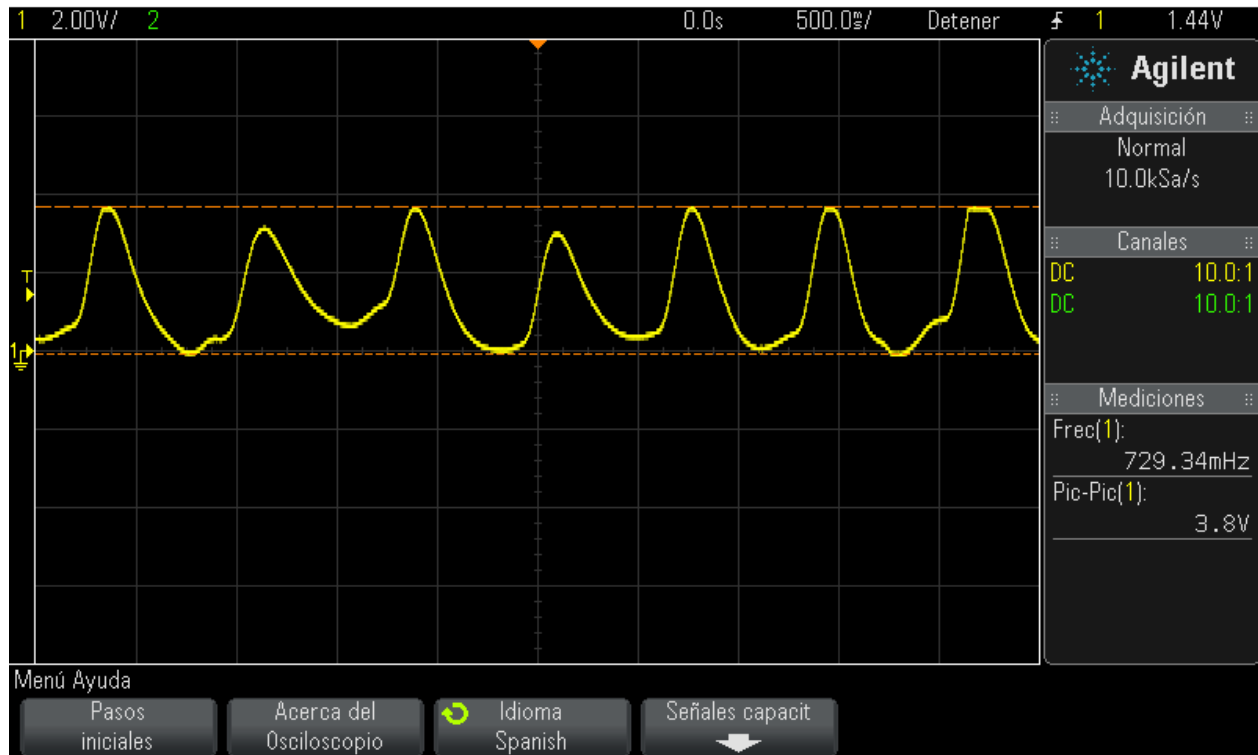


Figure 6- PPG circuit armed on a white protoboard. The infrared LED and the photodetector were putted face to face in order to measure the blood flow.

The signal obtained at the output pin of the circuit with a digital oscilloscope can be seen on the Graph 1. It can be seen that the maximum amplitude level is about 5 volts.



Graph 1- Signal obtained from the output of the circuit assembled on protoboard.

PCB manufacturing and implementation on Intel's Galileo.

Once the protoboard circuit was functional, the PCB files were sent to the lab in order to get it manufactured. After 3 days we received the PCB.

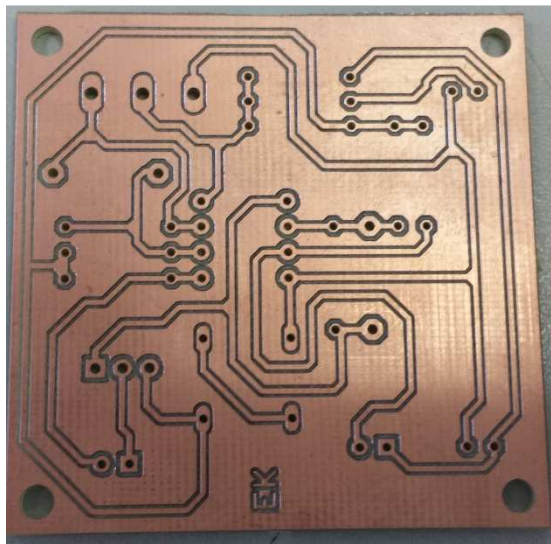


Figure 7- Project's PCB.



Figure 8- Back photo of the PCB.

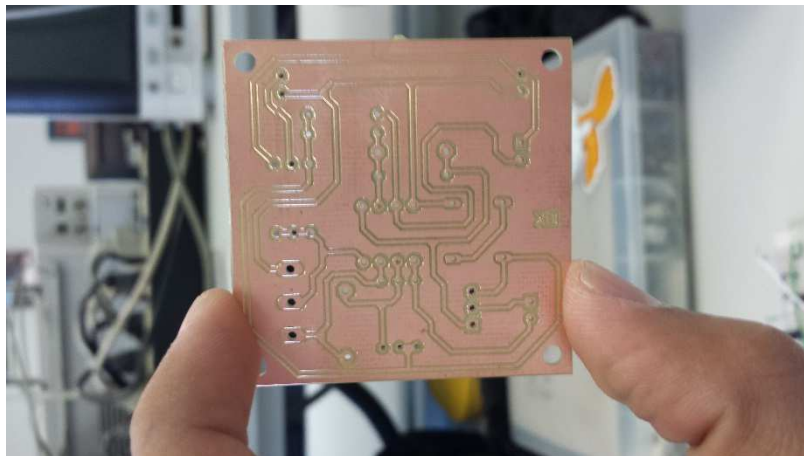


Figure 9- Frontal picture of the PCB.

Once received, the next procedure was to weld all the electronic components on it. It is important to note that the components can get damaged if they are exposed to high temperatures at long interval times (10 seconds approximately). Figures 12 and 13 illustrates the welding procedure. As shown, each component was welded with a little of welding paste.

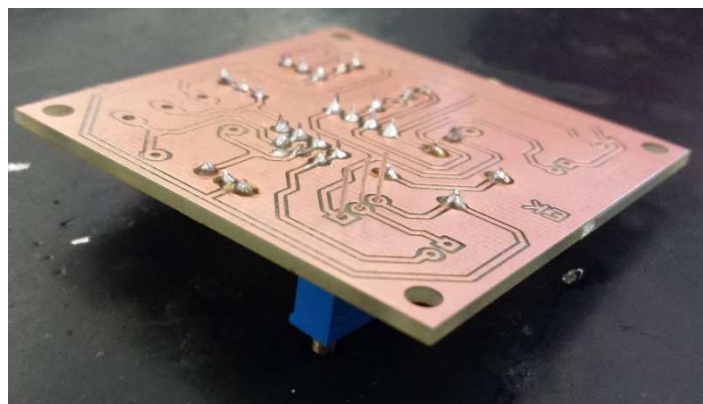


Figure 10- PCB on the welding process where the trimmer is not welded.

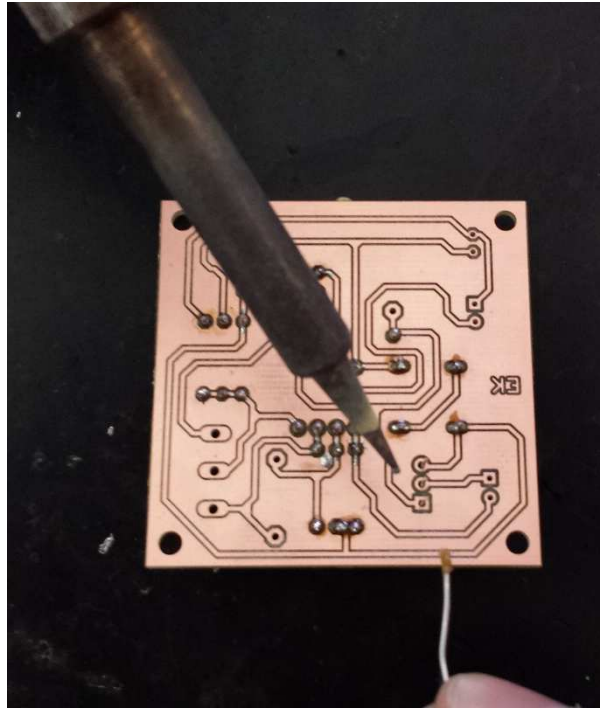


Figure 11- PCB on the welding process where the trimmer is being welded.

The welded PCB is shown on the figure 14.

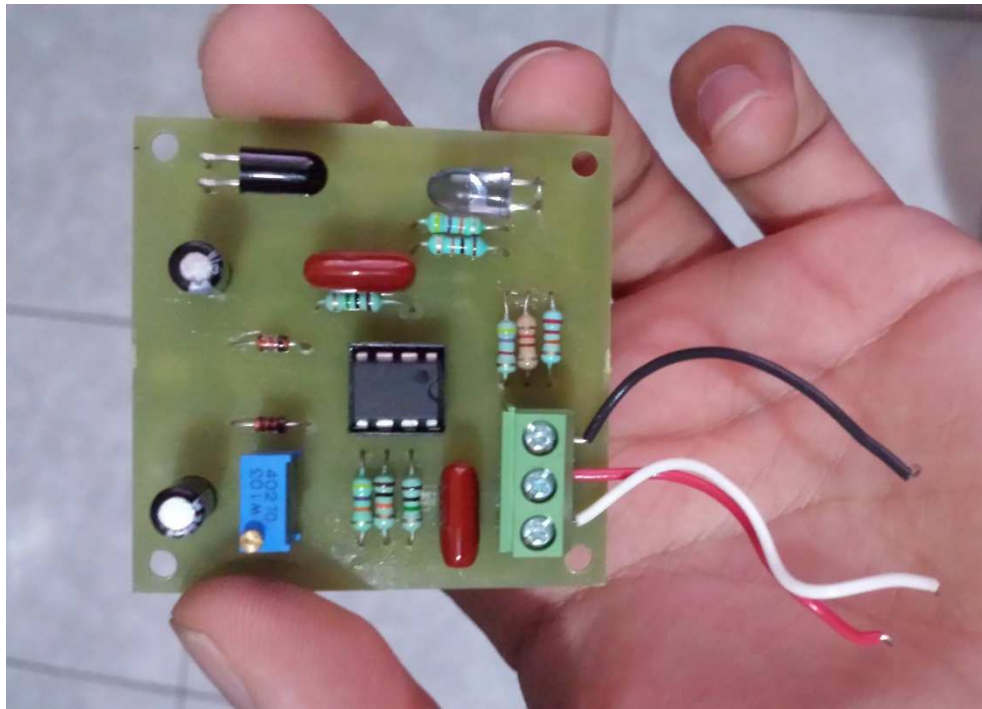


Figure 12- Printed circuit board of the PPG completely welded.

Once the PCB was completely welded it was connected to a digital oscilloscope and a voltage source (figure 15, 16) in order to verify that it was working correctly. The black cable on Figure 14 and 15 is used as reference while the red cable is the VCC connection. The white cable is the output of the circuit and was connected to the digital oscilloscope through the protoboard. The graph obtained is shown on Graphic 2.

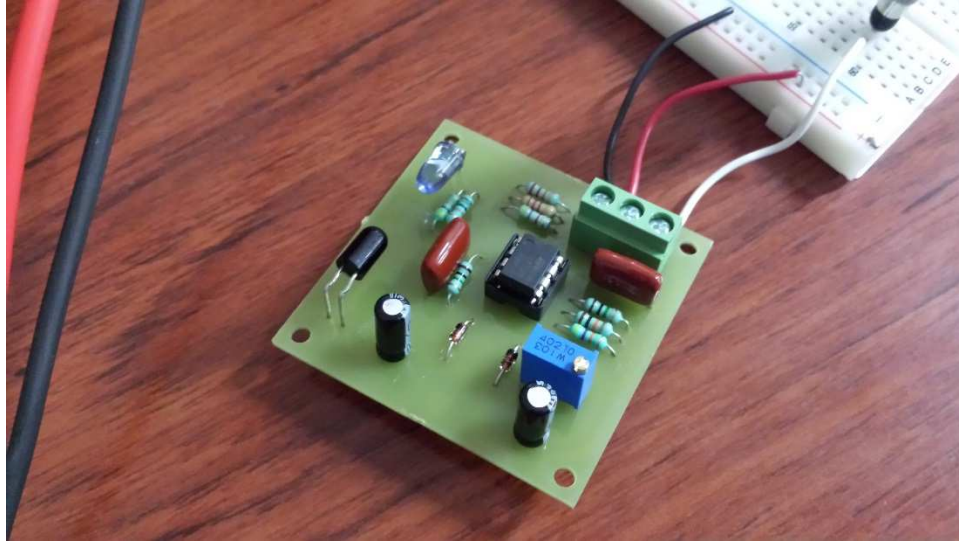
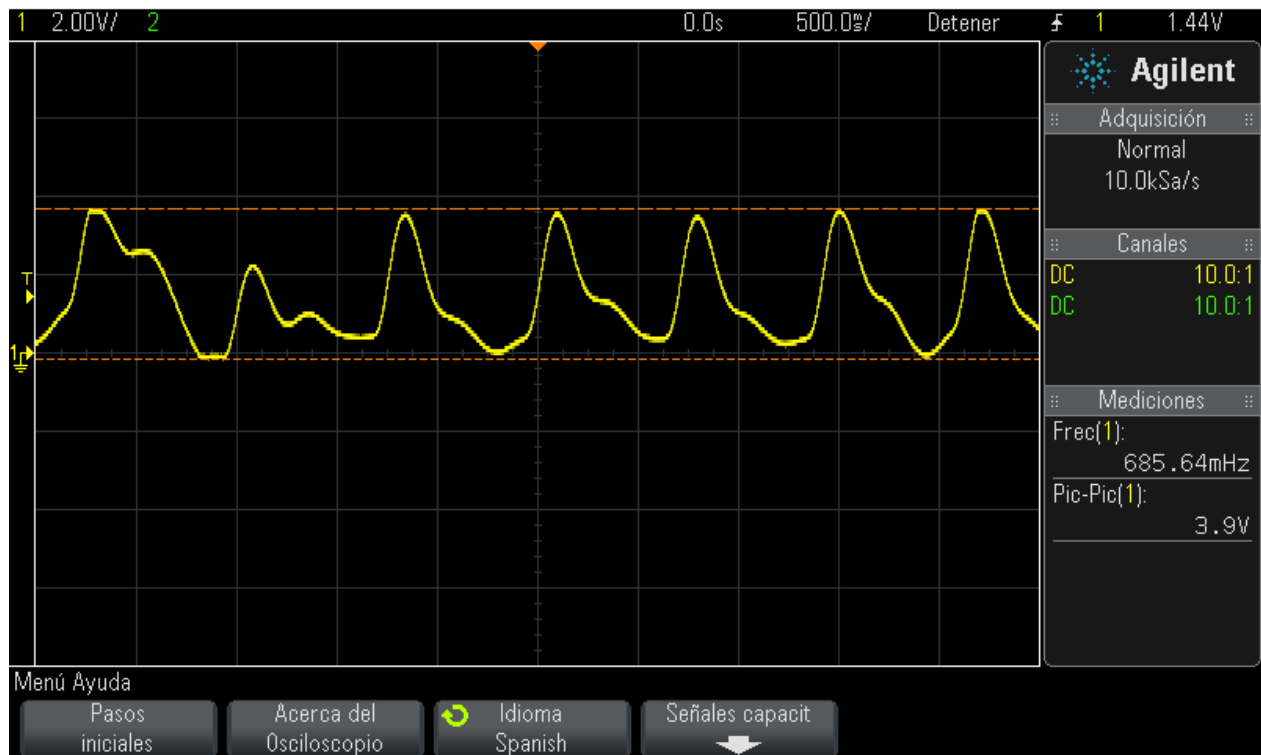


Figure 13- Printed circuit board of the PPG connected to the voltage source and the digital oscilloscope.



Figure 14- Voltage and current supplied from the Voltage source to the PCB.



Graph 2- Signal obtained from the output of the printed circuit board of the PPG.

Once the PCB was functioning as intended, it was connected to Intel's Galileo and to the computer. On Figure 17 it is shown how the PCB was connected while on Graph 3 the signal obtained on the computer is shown.

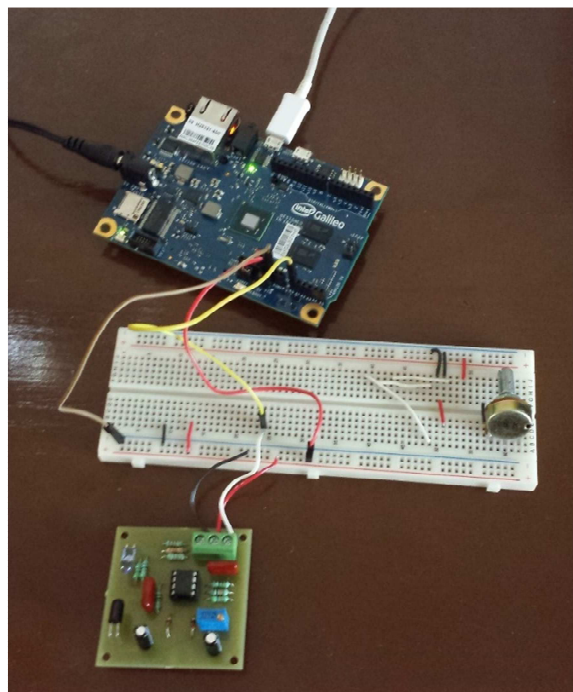
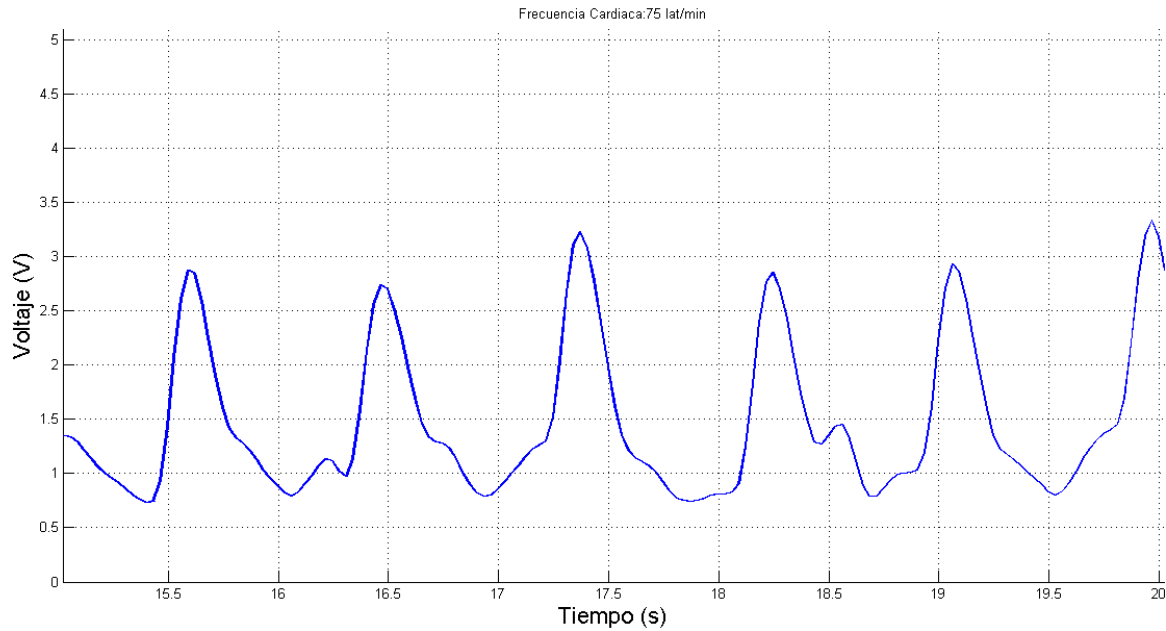


Figure 15- Connection between the printed circuit board and the computer through the Galileo.



Graph 3- Signal obtained from the PPG circuit through Galileo and Matlab.

After verifying that the PCB worked properly it was put in a plastic box that was acquired from the beginning of the project. On the next pictures the final appearance of the project can be seen.

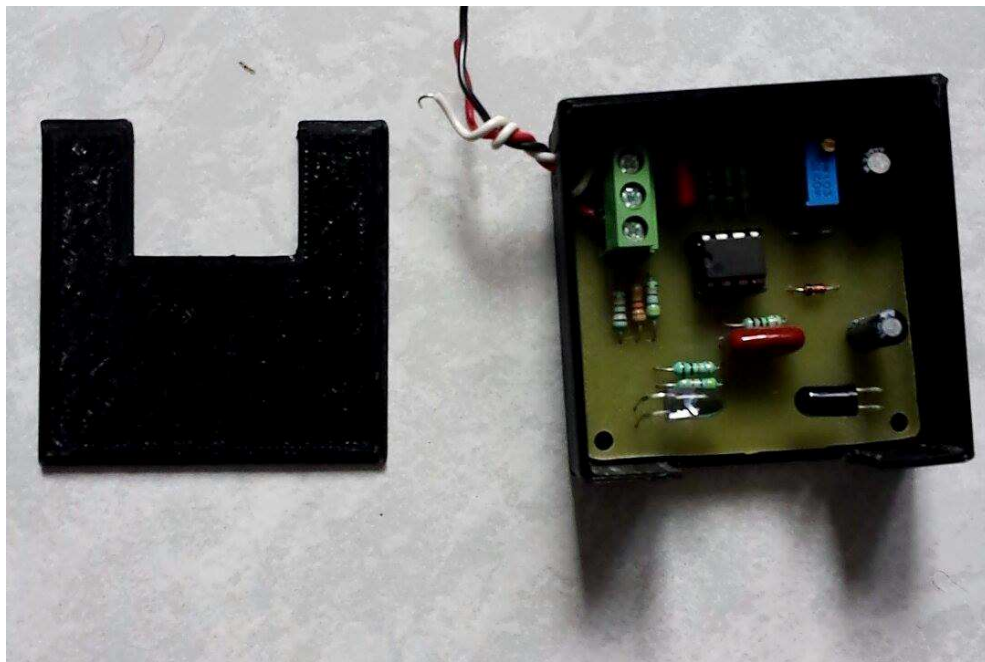


Figure 16. Top view of the project inside the plastic box.

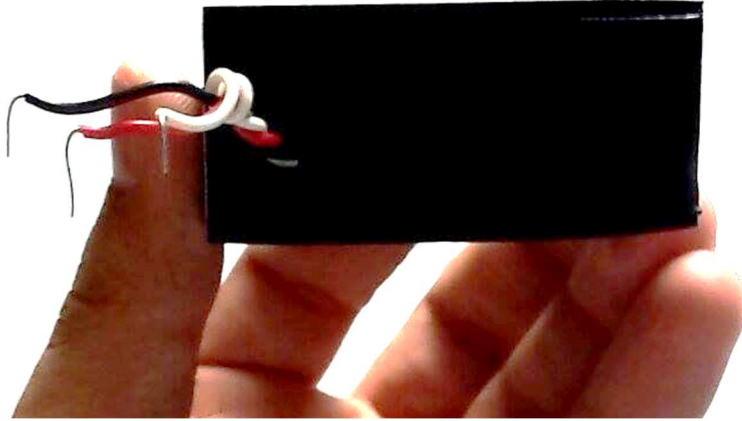


Figure 17. Lateral view of the plastic box which has inside the PCB. The red cable is for VCC, the black cable is for ground and the white cable is the output of the circuit.



Figure 18. Top view of the plastic box with the PCB inside the project.

Conclusions and result analysis.

The signal obtained with MATLAB (Graph 3) and the signal obtained from the digital oscilloscope (Graph 2) look almost the same, which means that all the information received from Intel's Galileo was received and interpreted correctly. The main objective of the project was to make a photo-plethysmograph device so that a user could know his BPM; this objective was completed successfully because the pulse of the user is correctly displayed on the computer and the BPM are correctly displayed.

The objective of this project could have been completed through other software instead of MATLAB such as Processing, but MATLAB was chosen because it is easier to receive and process data from the serial port and also it is easier to process it.

The main problem faced during the development of this project was to develop a program that could not only read and graph values through the serial port but also to be able to find the peak values of it and interpret them as beats per minute. This problem was solved looking for information and examples on the internet about MATLAB serial communication port and about Intel's Galileo serial communication.

One of the other problems that were faced during the project development occurred at the moment of welding because a component was welded on the wrong place. To solve this problem the component was removed taking care of not destroying the circuit bias. After it was removed, it was replaced with the correct component.

References

- [1] Toshiyo Tamura, Yuka Maeda and Masaki Sekine, "Wearable Photoplethysmographic Sensors—Past and Present," *Electronics* **2014**, 3(2), 282-302; doi:10.3390/electronics3020282 [Online]. Available: <http://www.mdpi.com/2079-9292/3/2/282>
- [2] Vekiel. (2015). *Pulse oximeter* [Online]. Available: <https://vekiel.com/medical-e-shop/diagnostic-instruments/pulse-oximetry/>
- [3] Intel. (2015). *Intel Galileo Board* [Online]. Available: <https://software.intel.com/en-us/iot/hardware/galileo/downloads>
- [4] Pico technology (2015): *Calculating the Heart Rate with a pulse plethysmograph* [Online]. Available: www.picotech.com/experiments/calculating_heart_rate/