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Design and development of a wearable medical smartwatch

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Abstract

The subject of my thesis concerns the hardware development of new functionalities inside a medical smartwatch, named PulsECG. PulsECG is an existing device that has been designed by Neuronica department of Politecnico di Torino, that measures ECG and blood oxygenation level. The goal was to use the knowledge acquired during the Electronic Engineering degree in order to develop a useful, practical and comfortable watch dedicated to the health of the user. In particular, the main objective was to add new functionalities in the watch without affecting size and wearability. The thesis is splitted in two activities: the first is to update the existing version of ECGwatch, a watch with the only goal to measure the user ECG. The second activity is to update the already existing PulsECG with new features.
PulsECG watch has kept the pre-existing functionalities: the measurement of the level of blood oxygenation and the ability to measure the main parameters of heart activity through an ECG graph on the smartphone application. The new smartwatch is also able to measure the body temperature of the user and has a motion sensor to adapt its functioning based on external factors.
A focused research phase of the components available on the market combined with the study of their datasheets enabled me to take the first steps of this project work. The post-Covid global crisis has caused the lack of availability of raw materials and electronic components. The research became even more difficult considering that many chips are not available swiftly and have very long delivery times. A trade-off was necessary between technical requirements and availability of components.
Secondly, I updated the schematics of the smartwatch making some adjustments to the PCBs through Cadence and Allegro softwares. Then, once assembled the boards I tested the new components using suitable firmwares loaded in the smartwatch in order to prove appropriate functioning. At the end of the whole activity, the smartwatch is suitable to measure ECG, SpO2, body temperature and movements. Thanks to a special software development on the smartphone application PulsECG, the user will have the opportunity to see the body temperature data (only ECG and SpO2 are currently visible).An additional work on the firmware can enable the smartwatch to detect if the user is wearing the device or it is in a resting or moving condition during the measurement. The information I have just provided are very useful to improve the battery life and also to understand if the measurements were made in right conditions.

Acknowledgements

Vorrei innanzitutto ringraziare il mio relatore Eros Pasero per avermi dato l'opportunità di lavorare nel team Neuronica su un progetto molto importante che, oltre a toccare temi di innovazione e tecnologia, è strettamente legato alla salute delle persone.

Ringrazio tutti i componenti del team: assistenti, dottorandi e gli altri tesisti con i quali ho avuto il piacere di confrontarmi e lavorare insieme.

Ringrazio i miei genitori e le mie sorelle per avermi sempre sostenuto e supportato nella realizzazione di questo progetto. Grazie per aver creduto in me.

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CHAPTER 1

Introduction

The market of wearable healthcare devices has exponentially increased in the last years. Due to the need of consumers to monitor their own health and better know themselves, the trend will continue to grow[1]. The high demand, in particular for smartwatches, brought the biggest technology companies to work together with medical industries in order to produce devices in great numbers. The businness is, as always in such cases, trying to build watches with more and more functionalities without affecting dimensions and comfort.
Once only used to count steps and tell time, smartwatches are now, in such cases, real medical monitoring devices with accurate healthcare tools. They allow users to read phone notifications or send simple messages, but also a wide choice of sports tracking and a constant monitoring of the main vital signs.
An example of how the businness has evolved is *Apple*. Leader in smartphone market, *Apple* launched the *Apple Heart Study* application in 2017 to monitor user 's heart rhythms with its smartwatch and alert those who are experiencing atrial fibrillation[2]. The race of the major companies for lead the wearable fitness market, has brought benefits also on the wearable healtcare technology. Mainly focused for medical uses, wearable healthcare technologies are all the electronic devices designed to collect the data of user 's health. These devices can send information to a doctor or other healthcare clinics in real time, for a better patient monitoring and patologies analysis.

The work done and described in this paper was to increase the number of functionalities of an existing medical watch at the Polytechnic University of Turin. Its name is PulsECG and it measures blood oxygenation and electrocardiogram. With this thesis, a temperature sensor and an accelerometer were added to the watch. This will also allow the user's body temperature and movements to be monitored to optimize its use. The next chapters will review the status of medical watches to date, going into more detail about the main measurements they perform. Next, what PulsECG is and how it is to be improved will be explained.
All the components chosen and present on the electronic boards will be listed and

justified, illustrating the schematics and drawings of the design. The last chapters are devoted to the tests performed on the new PulsECG and possible further improvements that could be worked on.

CHAPTER 2

State of art

2.1 Medical wearable market trend

A research done by Grand View Research estimate that the growth of the medical wearable devices market in U.S will increase about 25.7% per year until 2030 [3].

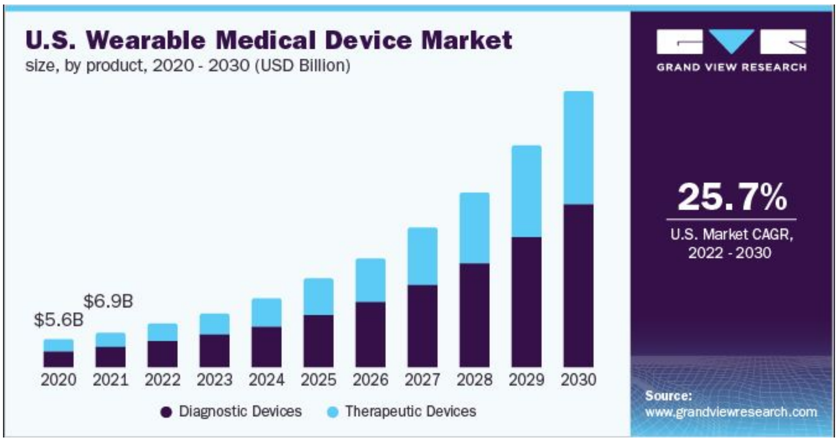


Figure 2.1: Wearable medical trend in U.S.

The diagnostic devices segment has driven the market in 2021 with a revenue share of 62.2%. More in detail, the smartwatches segment dominated the wearable medical devices market and is likely to remain dominant for the next years. Due to the increasing average age in the population and the need to reduce health care spending, another sharply rising index is that of the home and remote patient monitoring.
One of the main drivers of this trend is undoubtedly the Covid-19 pandemic effect which has led to increased awareness of personal health monitoring. Not only that, several companies in the industry have also given their products a makeover, developing them specifically to detect possible symptoms of viral actions.
Another determining factor in the development of this market is the need of a constant monitoring of some diseases such as diabetes and hypertension. For these examples,

is required a continuous monitoring of various physiological parameters as blood sugar levels and blood pressure. These types of diseases are expected to increase over the next few years, all due to the sedentary lifestyle that characterizes our society.

2.2 Smartwatch features on the market

The spread of the smartwatch instead the traditional ones pass through the willingness of the people to taking care of yourself and easily discover its state of health[4].
The main features supported by current smartwatches are:

- The opportunity to have a window of the main smartphone utilities: the user can see notifications, write simple messages, manage music or GPS apps.
- Record and give a lot of information when the user enjoy sports. He can see the duration of the physical activity, the distance covered, other path information, the calories burned etc.
- The availability at any time of some vital parameters like the heartbeat, SpO2 saturation, oxigen volume per minute (VO2MAX) and blood pressure.

Any smartwatch model allow the user to see and share his data directly on his smartphone. If on the one hand people can better discover their body, taking interest about their health, the biggest opportunity of this technology is the greater ease of use in medical applications. Medical wearable devices in some cases can replace big and uncomfortable equipments, making easier read and control a lot of vital parameters of patients.

2.3 ECG and SpO2 measurements

In this section a general explanation how to read and undestand ECG and SpO2 measurements.

2.3.1 Electocardiogram

The electrocardiogram is the graphical representation of the heart electrical activity. Potential differencies of Myocardium pulses are propagated along the human body and they can be acquired by electrodes on the skin. A typical ECG segment is characterized by waves and segments briefly explained below [5].

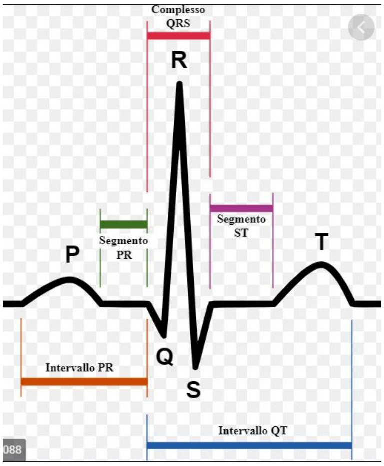


Figure 2.2: A typical ECG pulse

P WAVE It is the first wave of the segment and identifies the atrial depolarization (atrial electrical activation). The duration ranges between 60 and 120 ms, the amplitude is not higher than 2,5mm.

PR INTERVAL The interval between the begin of the P wave and the begin of the QRS compound. It represents the necessary time for the atrial depolarization to reach ventricles.

QRS COMPLEX It identifies the ventricular depolarization. The whole duration is between 60 and 90 ms.

Q WAVE First negative deflection. The wave has a small size and corresponds to the interventricular depolarization;

R WAVE First positive deflection. It represents the depolarization of the left ventricle.

S VAWE Second negative deflection. It has low size like Q wave and shows the depolarization of the left ventricle back part.

ST PATH The distance between S wave and T vawe, it represents the time interval between the ventricular depolarization and the ventricular repolarization. Electrical movements are not detactable here. That means an ST path ideally a flat line at height 0. A little variation of 1 mm is still accepted.

T WAVE The first positive wave after the QRS compound, it represent the ventricular ripolarization. The repolarization is the recovery of the base electric conditions. This little wave is not always visible.

QT INTERVAL The distance between the begin of the QRS compound and the end of T wave. It identifies the whole ventricular electrical activity. The duration depends by the heart rate, it is usually between 350 and 440ms.

2.3.2 The heart rate (HR)

The heart rate is defined as the number of heart beats that occur in one minute (bpm). Usually, the heart rate in normal conditions goes from 60 and 100 rpm. There are different methods to evaluate the heart rate through the heart trace: the easiest is to divide 300 for the number of the square between two R waves. In figure, an example of a heart rate of 85 rpm measured from an ECG trace.

Figure 2.3: Heart-rate evaluation from ECG

A preliminary evaluation consist of check, along the trace, if the time interval between the R waves has always the same width. A constant periodic pulse without variations is the first symptom of heart in good health (variations at most of 2 fractions of square are accepted). The second characteristic to see is the presence and the shape of the P wave. The heart rithm can be defined as sinusoidal rithm if the P wave is located before the QRS compound and it is positive. If the P wave is negative oriented is probable that the two electrodes are inverted (the watch read signals with opposite sign). If the position of the electrodes are good, it is possible that the patient is suffering of atrial tachycardia. In the case the P wave is located after the QRS compound, it is a symptom of ventricular or supraventricular arrhythmia. The presence of an irregular rithm and a not clear and visible P wave is due to an atrial fibrillation. This arrhythmia is defined as a chaotic electric atrial activity causing a not efficient contraction of the heart walls.

2.3.3 Oxygen saturation

The oxygen saturation is a blood characteristic that indicates the percentage of haemoglobin full of oxygen respect the total number[6]. In standard conditions, during the breath, red blood cells full of haemoglobin take the oxygen to transport it. Standard levels of SpO2 is between 95% and 100%. Lower values of are defined as hypoxemia. This status can be taken by cardiopulmonary criticality, sleep apnea, some medicines or high altitude[3]. Common sympthoms are migraine, high heart rate, cough or cyanosis. Iron efficiency can be another cause of low oxygen saturation. For this reason, a good diet can increase the SpO2 value.

The measurement of this parameter is done thanks two different sections of the sensor: the transmitter and the receiver. The transmitter is composed by a led that emits light into the finger. Haemoglobin with oxygen absorbs infrared light, heamoglobin without oxygen absorbs red light. The receiver collect all the reflected light not absorbed by the finger. The difference between the emitted and received light allow the sensor to evaluate the percentage of SpO2 in blood.

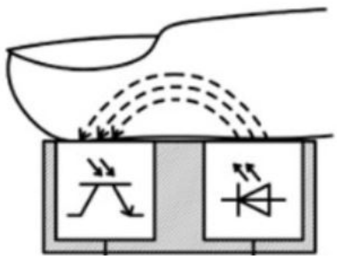


Figure 2.4: SpO2 measurement description

2.3.4 Body temperature

The temperature of the superficial skin is strongly influenced by environmental conditions and clothing, especially at the extremities (hands and feet) [7]. To give an idea, if the ambient temperature is 20°C and the clothing light, the temperature at the level of the arms drops to 32°C, and on the outermost skin layers the temperature ranges from 28°C (fingertips). Also, these values mentioned above are only a point of reference, but each person has different temperatures. Some factors on which body temperature depends are:

- Ambient temperature
- characteristics of the individual person (gender, age)
- Nutrition
- Training and physical activity

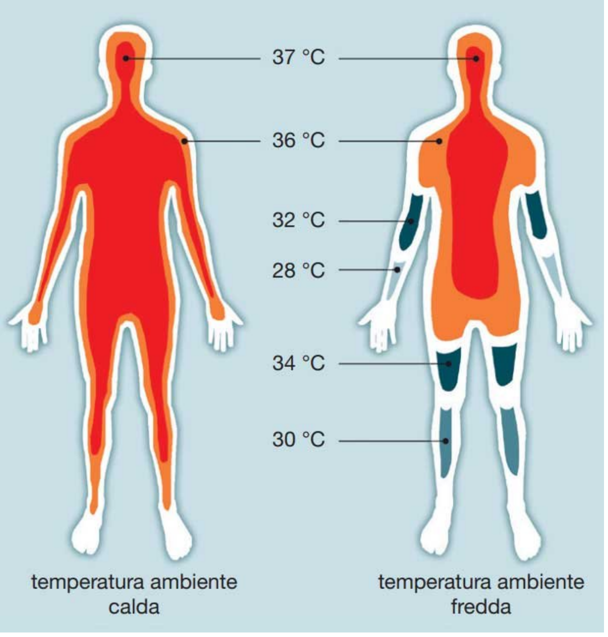


Figure 2.5: Body temperature [8]

For these reasons, each of us can have different temperatures from another, even though they are both healthy. One way to be able to estimate one's body temperature is to use Liebermeister's rule [9]. This rule shows how the heart rate is strongly influenced to body temperature: the heart rate increases by 8-10 beats per minute for every degree centigrade the user has relative to his or her base temperature [10]. Long term monitoring could make the watch capable of detecting the user's resting body levels and help with heart rate measurements to refine the body temperature measurement.

CHAPTER 3

PulsECG

3.1 General description

PulseECG [11] is a smartwatch built in Politecnico di Torino in Neuronica department. It is developed to perform two vital measurements:

- The electrocardiogram, giving the heart trace and the heart rate value.
- The oxigen saturation in blood (SpO2).

The watch is composed by two printed circuit boards: the biggest board has the energy management components, the microcontroller and ECG filter section. The second board has the oxygen saturation measurement with the SpO2 sensor. Flat wires allow the electrical connection between the PCBs.

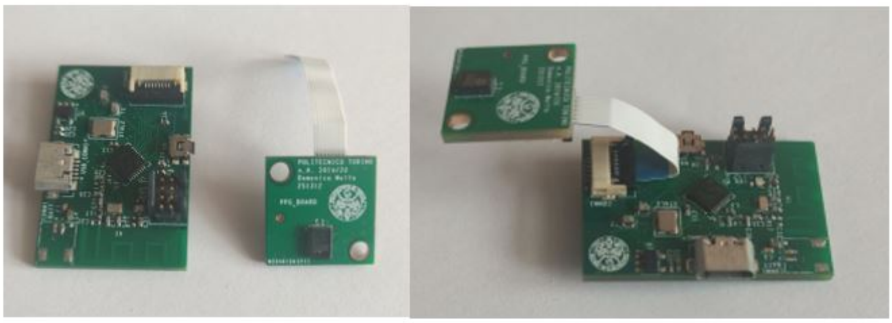


Figure 3.1: First version of PulsECG

There are also two electrodes: they are the interface of the watch with the user. One electrode is located on the bottom side of the watch, in contact with the wrist. The other one, on the upper side, is in contact with the user only when it is touched with a finger. Signals received from electrodes will be filtered and elaborated by the ECG board and microcontroller.

3.1.1 Smartphone application description

The watch is connected though Bluetooth connection with the smartphone application PulsECG, that processes the data sent by the watch and shows to the user the ECG and SpO2 graphs. Charts are stored in an archive with data and hour of the measurement. The homepage application has three main windows:

Seleziona il dispositivo. When selected, a new window opens in order to find and connect the PulsECG with the phone through bluetooth.

Acquisisci. When pressed (with watch connected), the application is ready to receive data packets and the user can run the watch. It is in waiting mode until the finger of the user is not on the upper electrode. Then, PulsECG starts the heart rate measurement.

Archivio. In this folder there are all the measurements done in the past by the user, with data and plots.

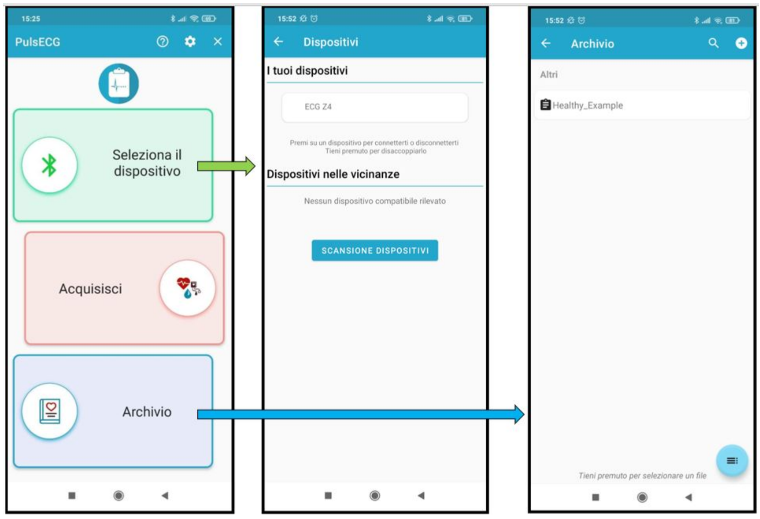


Figure 3.2: Application manù

The application generates the plots of heart rate and oxygen saturation thanks the data received from PulsECG.
An example in the next page.

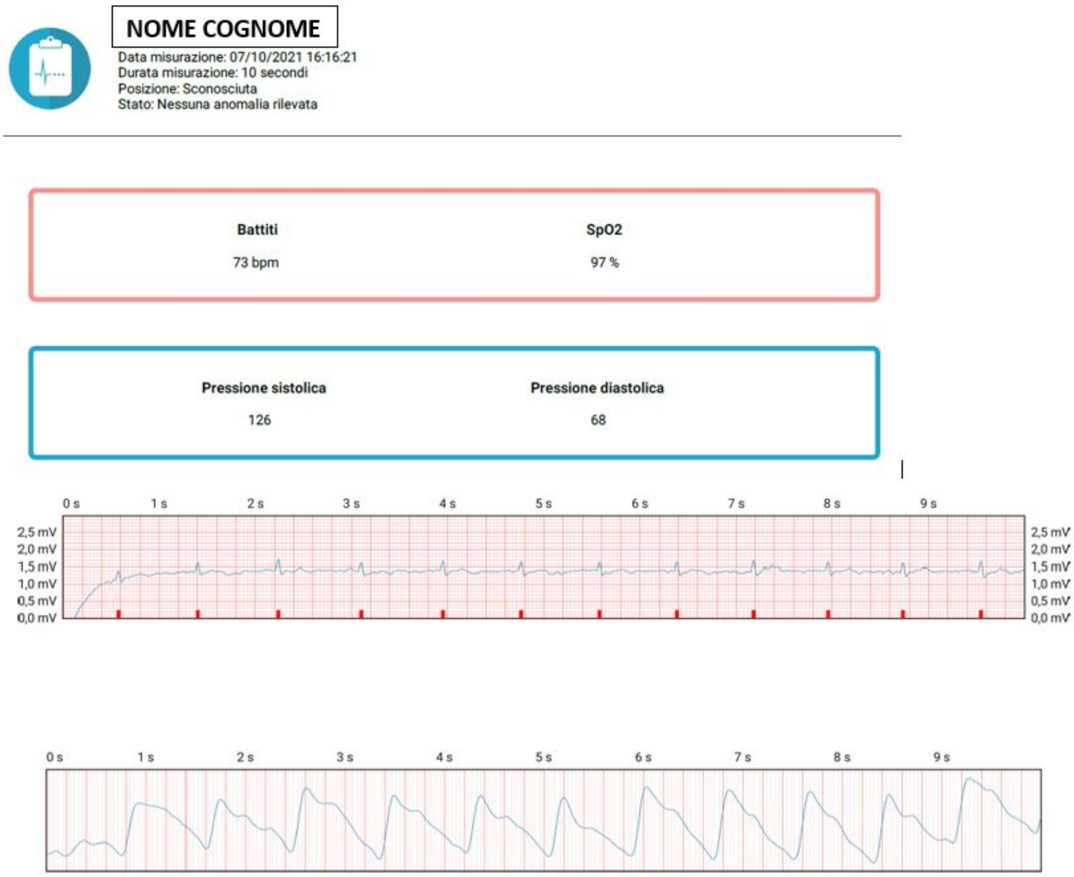


Figure 3.3: ECG and SpO2 plots

3.2 Operating principle

The operating principle is based on the difference of electrical pulses that pass through electrodes. The signals are readed with the analog to digital converter (ADC) of the microcontroller and the data are stored and sent to the smartphone application. In the meantime, when the finger touches the upper electrodes, the SpO2 sensor can read the oxigen saturation.
The steps the user has to do for a correct measurement are the following:

1. Wear the watch in order to put the bottom electrode on the wrist.
2. Open PulsECG application and connect the watch with the smartphone
3. On the application menu, press *acquisisci*
4. Lean a finger of the hand on the upper electrode and stay as still as possible. Now the data acquisition starts.
5. When the measurement ends, the smartphone application returns ECG and SpO2 plots.

Figure 3.4: Operating principle scheme

3.3 Description and goals of new PulsECG project

The goal of the activity is to add and implement new functionalities inside PulsECG. New functionalities mean a re-design of the existing printed circuit board whith new sensors and secondary components. The two main additions are the temperature body sensor and an accelerometer for the motion detection. Together with these big additions, other improvements are done: there are a new bigger push button for a better feedback during the pressure, a new JTAG interface and a battery switch for a manual cut-off of the supply.

3.3.1 Body temperature sensor

The monitoring of the body temperature is one of the two functionalities to add: it is an essential parameter for medical watches. The sensor is connected to the electrode in contact with the skin in order to read the temperature of the user when is dressing the watch. For this implementation a new dedicated PCB is designed. It doesn't increase the surface needed for the watch beacuse it is placed exactly on bottom of the ECG board.

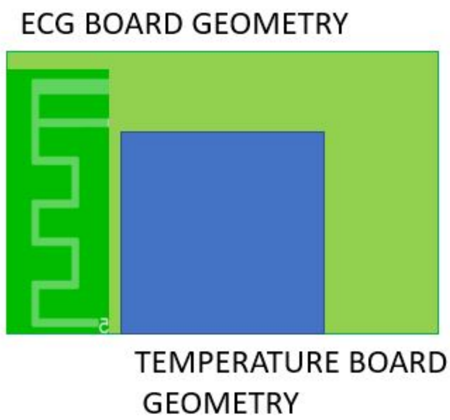


Figure 3.5: Temperature board geometry

3.3.2 Motion detection

The second characteristic that we will add is the motion detection. Thanks an accelerometer, PulsECG can elaborate every data concerned the movement of the user. In example, it can know if the user:

- is dressing or not the watch
- is dressing the watch in non-stress condition

- is dressing the watch in under stress condition

This information can be very useful for two reasons:

- Improving the quality of the heart rate and oxygen saturation measurements. Data under-stress or at rest are very different.
- Improving the energy management strategy in order to increase the battery life. If the user is not dressing the watch, it can go in sleep mode.
- Detect falls os sickess of the user

The accelerometer is placed on the ECG board, near the push button, without the need to increase the board size.

3.3.3 Flash memory

Thinking about the nexts steps of feature implementations, a lot of data will be stored during the watch operations. In particular, the presence of the accelerometer may imply a continuous measurement and data storing. For this rason, a flash memory is placed on the PPG board, mantaining the same size of the PCB. The PPG board with the memory has not be tested during the validation phase because a simple PPG board without the memory is used. This implementation is only precautionary for other future watch improvements.

3.3.4 JTAG interface

The introduction of the temperature board increases the vertical space of the watch, so it is foundamental minimize its height. A change of the JATG interface, passing from a connector to flat pads, reduce the height of the ECG board and makes it possible the temperature board connection. Having only pads on the board, a fourth PCB is necessary: it converts the JTAG connector of the launchpad into pogo pins able to program the microcontroller of the watch.

3.3.5 Battery switch

In the current firmware version of the watch, it goes to sleep after a fixed time of inactivity and it turns on when the push button is pressed. With the presence of a physical battery switch, the user can turn on and turn off the watch manually. Indipendently of the position of the switch, the battery is always rechargeable.

CHAPTER 4

ECGwatch

4.1 General description

ECG watch is a smartwatch developed by Politecnico di Torino dedicated exclusively to the measurement of user 's electrocardiogram. It has no other functionality: it acquires the user's heart signals through two electrodes. Subsequently, data are stored and sent via bluetooth to the smartphone application. Through the application, the user can view and share the ECG traces with anybody they wish, at any time.

4.2 Description and goals of ECGwatch project

The most relevant technical novelty of the new version of the smartwatch concerns the analog interface that filters the signal received from the electrodes. Since PulsECG watch gave very good results from the point of view of filtering and representation of the ECG tracing, it was decided to use the same front-end also for the new version of ECGwatch. More generally, it was decided to take the entire PulsECG hardware as a starting point for the new ECGwatch design, removing excess hardware. ECGwatch therefore has all the novelties and features already described for PulsECG, except that it does not have all the additional functionality to the ECG measurement.

CHAPTER 5

PULSECG: hardware implementation

The PulsECG hardware implementation involves the separate development of 4 electronic boards:

- ECG board: the main board, the largest. It includes the power management, data processing and ECG interface sections.
- PPG board: in this board there is the PPG sensor and, in this new development, also a flash memory.
- Temperature board: the electronic board on which the temperature sensor is mounted.
- JTAG board: it allow the firmware upload through the launchpad.

5.0.1 Choice of the components

The choice of some components has been strongly influenced by the great raw material emergency we have been experiencing in recent years. Many common electronic components are no longer available or have lead times that are not in line with project targets. Therefore, in some circumstances, the choice of component had not only technical, but also logistical reasons.

5.1 ECG board

5.1.1 Microcontroller CC2640R2F

Figure 5.1: CC2640R2F - Texas Instruments microcontroller

Description

CC2640R2F microcontroller is part of the family of Texas Instruments microcontroller supporting Bluetooth 5.1 low energy [12]. The purpose of this BLE protocol is to guarantee a strong and reliable Bluetooth connection with less power consumption compared to the previous version of bluetooth protocols.
A good trade-off between the number of GPIO pins (10) and the size of the package, make this microcontroller a good choice for the project. Component inherited from the previous PulsECG version, with an already developed firmware.

Main features

- Arm® Cortex®-M3
- 2.4 GHz RF transceiver compatible with Bluetooth® Low Energy 5.1
- Up to 48-MHz clock speed
- 128KB of in-system Programmable Flash
- RoHS-compliant packages: 4-mm × 4-mm RSM VQFN32 (10 GPIOs)
- Normal operation voltage: 1.8 to 3.8 V
- Standby: 1.1 uA with RTC running and RAM/CPU retention
- 12-bit ADC, 200-ksamples/s, 8-channel analog MUX
- Communication protocols: UART, I2C, and I2S

Pinout and package

RoHS-compliant packages: 4-mm × 4-mm RSM VQFN32 (10 GPIOs).

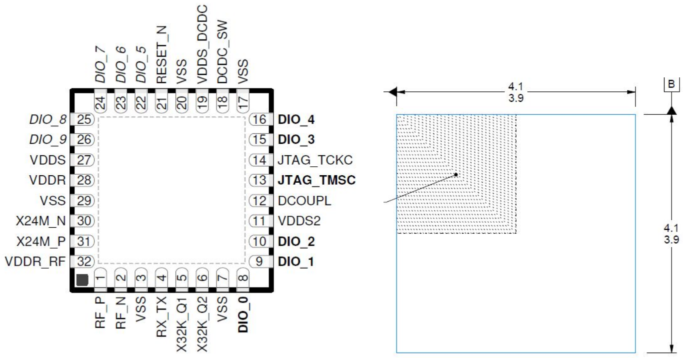


Figure 5.2: CC2640R2F: pinout and dimensions

5.1.2 BLE antenna

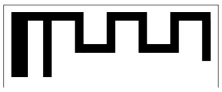


Figure 5.3: BLE antenna as Application Note AN043

Description

CC2640R2F datasheet gives all the informations in order to design a correct antenna routing. Furthermore, Texas Instruments suggests through the application note AN043 a bluetooth antenna that can be routed for a good BT connection [13].

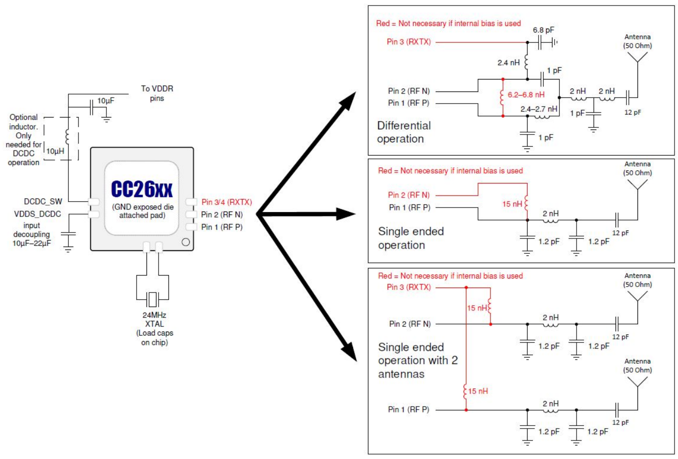
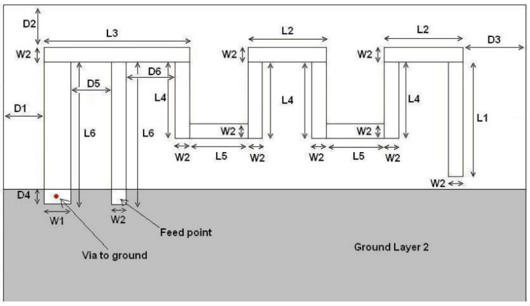


Figure 5.4: Antenna schematic options

Layout



L1	3.94 mm
L2	2.70 mm
L3	5.00 mm
L4	2.64 mm
L5	2.00 mm
L6	4.90 mm
W1	0.90 mm
W2	0.50 mm
D1	0.50 mm
D2	0.30 mm
D3	0.30 mm
D4	0.50 mm
D5	1.40mm
D6	1.70 mm

Figure 5.5: Antenna AN043 design

Schematic

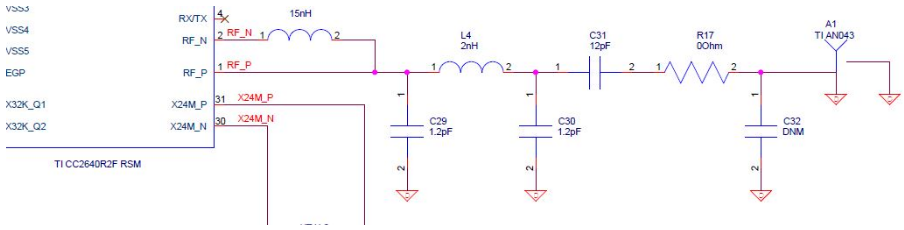


Figure 5.6: Antenna schematic

5.1.3 Acccelerometer Memsic MXC6655XA

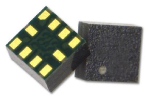


Figure 5.7: MEMSIC MXC6655XA - 3-axis accelerometer

Description

MXC6655XA is an ultra-low power, lownoise, integrated digital output 3-axis accelerometer with a feature set optimized for wearables and consumer product motion sensing [14]. For the use case thought in the watch, it is not necessary have an accelerometer so accurate or wwith a big range of measurement: it must measure mainly falls or inactivities. So, MXC6655XA was the cheapest and smallest accelerometer available during the choice. This is one of the choice strongly influenced by the shortage of materials. Initially, the accelerometer identified for the project was the MEMSIC

3635. During the board design it has ended its availability, forcing me for a change in progress with the accelerometer most like him, MXC6655XA.

Main features

- Operating voltage limits: from 1.8V to 3.6V
- ±2, 4, 8 ranges with 12-bit resolution
- Communication protocols: I2C and SPI

Pinout and package

Package information: LGA-10, 1.6mm (E) × 1.6mm (D) × 0.94 mm 10-pin package.

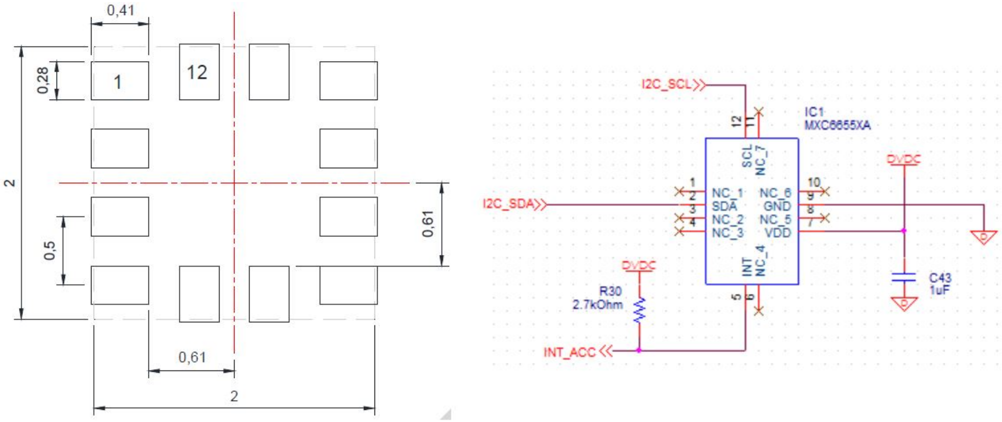


Figure 5.8: MEMSIC MXC6655XA - 3-axis accelerometer

Schematic

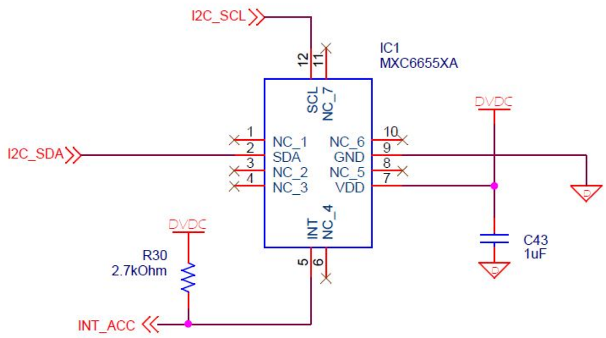


Figure 5.9: Accelerometer schematic

5.1.4 Battery MIKROE-2759

Figure 5.10: Battery MIKROE-2759

Description

Li-Polymer Battery is the best solution for adding an autonomous and stable power supply to your devices that require mobility and long-lasting energy source. With its 4.5g approximate weight, it is a compact and reliable power source [15].

Main features

- Nominal voltage: 3.7V
- Voltage at end of discharge: 3.0V
- Capacity: 190mAh
- Charging voltage: 4.2V
- Connector: JST-SHR-02V-S

Dimensions

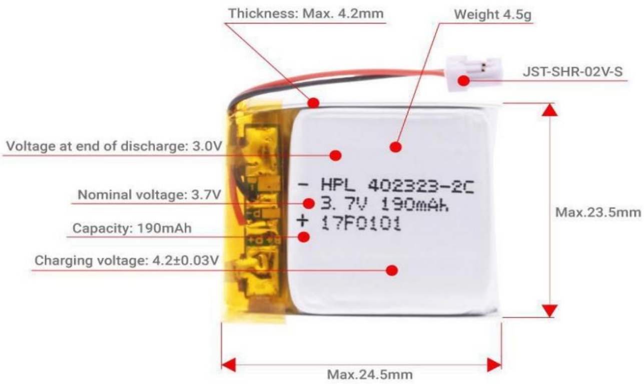


Figure 5.11: Battery MIKROE-2759

5.1.5 Battery gauge module MAX17048

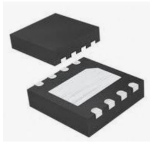


Figure 5.12: Gauge module MAX17048

Description

MAX17048 is a tiny, micropower current fuel gauges for lithium-ion (Li+) batteries in handheld and portable equipment. It uses the sophisticated Li+ battery-modeling algorithm ModelGauge™ to track the battery relative state of charge (SOC) continuously over widely varying charge and discharge conditions.
The ModelGauge algorithm eliminates current-sense resistor and battery-learn cycles required in traditional fuel gauges. Temperature compensation is implemented using the system microcontroller [16].

Main features

- Precision ±7.5mV/Cell Voltage Measurement
- Ultra-Low Quiescent Current (3uA Hibernate, 23uA Active)
- I2C Interface

Pinout and package

Package information: 2.1mm(D) x 2.1mm(E)

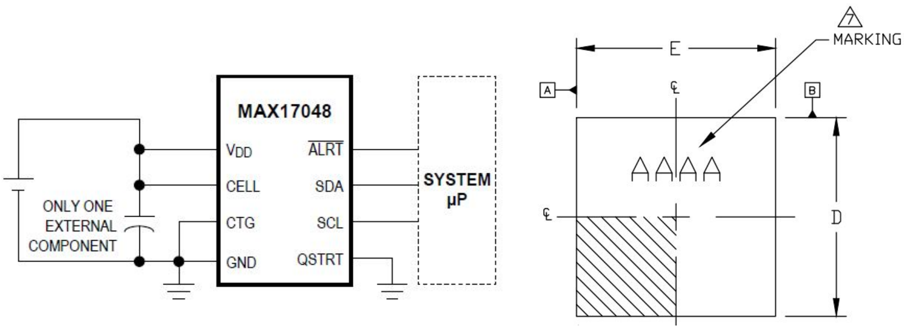


Figure 5.13: Battery gauge module MAX17048: pinout and package

Schematic

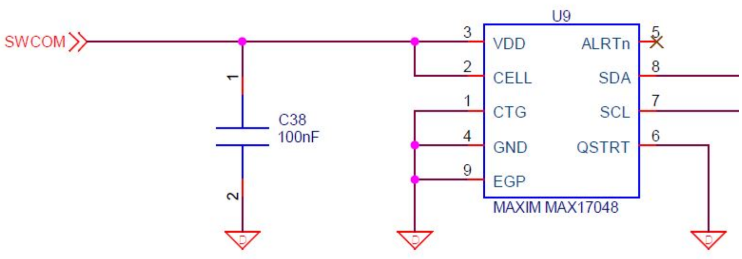


Figure 5.14: MAX17048 schematic

5.1.6 Battery charger module MAX1555

Figure 5.15: Charger module MAX1555

Description

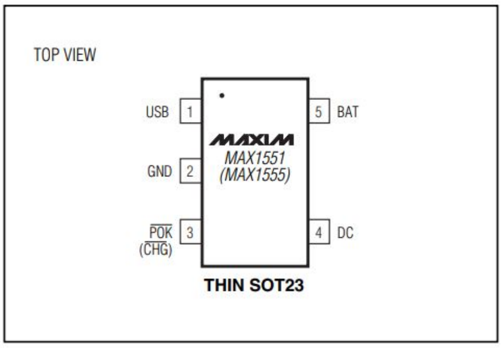
The MAX1551/MAX1555 charge a single-cell lithium-ion (Li+) battery from both USB* and AC adapter sources. With USB connected, but without DC power, charge current is set to 100mA (max). This allows charging from both powered and unpowered USB hubs with no port communication required. When DC power is connected, charging current is set at 280mA (typ). The MAX1551/MAX1555 are available in 5-pin thin SOT23 packages and operate over a -40°C to +85°C range [17].

Main features

- Charge from USB or AC Adapter
- On-Chip Thermal Limiting Simplifies Board Design
- Charge Status Indicator

Pinout and package

Package: 5 pin Thin SOT23-5



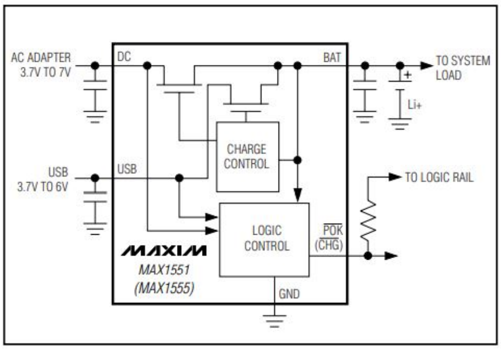


Figure 5.16: Charger module MAX1555: pinout and typical circuit

Schematic

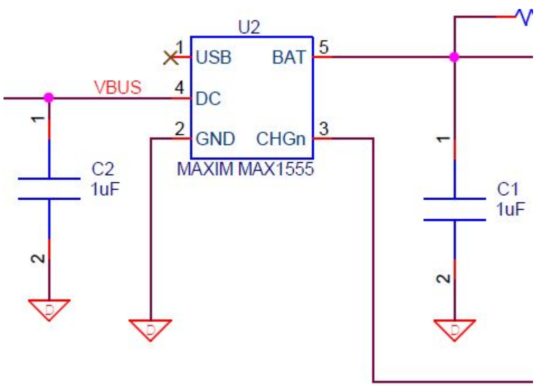


Figure 5.17: MAX1555 schematic

5.1.7 Voltage regulator MAX1759

Figure 5.18: Voltage regulator MAX1759

Description

The MAX1759 is a buck/boost regulating charge pump that generates a regulated output voltage from a single lithium-ion (Li+) cell, or two or three NiMH or alkaline cells for small hand-held portable equipment [18].

Main features

- Regulated Output Voltage (Fixed 3.3V or Adjustable 2.5V to 5.5V)
- 100mA Guaranteed Output Current
- +1.6V to +5.5V Input Voltage Range
- Low 50uA Quiescent Supply Current
- 1uA Shutdown Mode
- Short-Circuit Protection and Thermal Shutdown

Pinout and package

Package information: 5,05mm(E) x 3,05mm(D1) x 1,1mm(A)

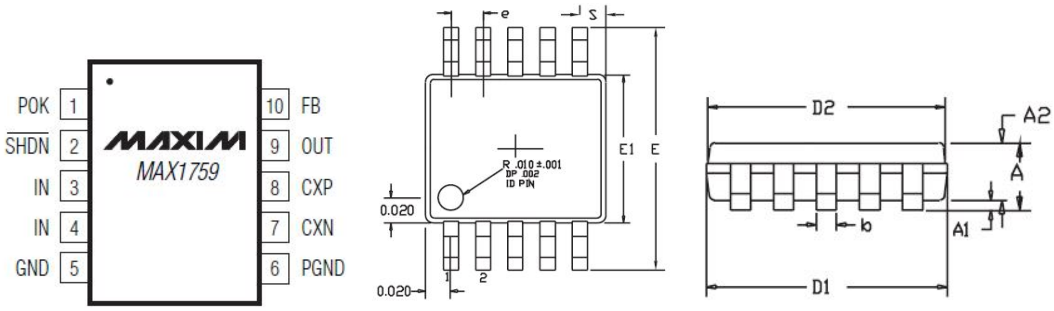


Figure 5.19: Voltage regulator MAX1759: pinout and typical circuit

Schematic

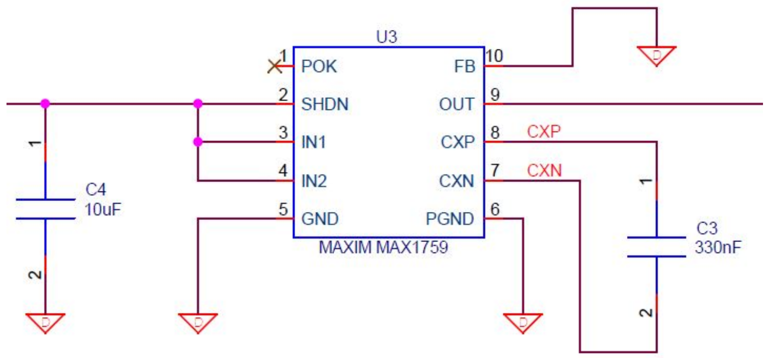


Figure 5.20: MAX1759 schematic

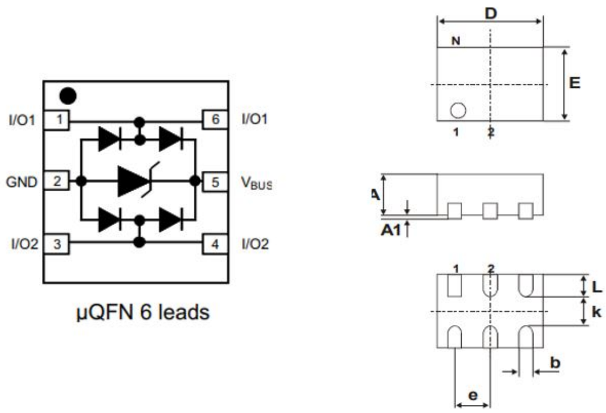
5.1.8 ESD protection DVIULC6-2M6

The DVIULC6-2M6 [19] is a specific discrete device dedicated to ESD protection of high speed interfaces. Its ultra low line capacitance secures a high level of signal integrity without compromising in protecting sensitive chips against the most stringently characterized ESD strikes. It is a crucial component regarding the analog ECG interface, where signals are very sensitive.

Main features

- 2-line ESD protection (at 15 kV air and contact discharge, exceeds IEC 61000-4-2)
- Ultra low capacitance: 0.6 pF at F = 825 MHz
- Low leakage current: 0.5 µA max
- Fast response time compared with varistors

Pinout and package



Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A	0.50	0.55	0.60	0.020	0.022	0.024
A1	0.00	0.02	0.05	0.000	0.001	0.002
b	0.18	0.25	0.30	0.007	0.010	0.012
D		1.45			0.057	
E		1.00			0.039	
e		0.50			0.020	
K	0.20			0.008		
L	0.30	0.35	0.40	0.012	0.014	0.016

Figure 5.21: DVIULC6-2M6 pinout and package

Schematic

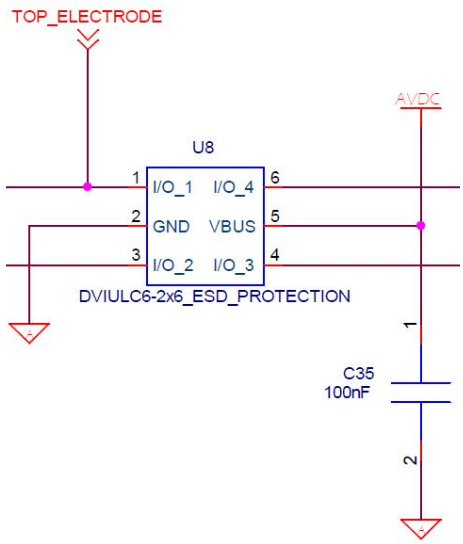


Figure 5.22: DVIULC6-2M6 schematic

5.1.9 Amplifier INA333

The INA333 [20] device is a low-power, precision instrumentation amplifier offering excellent accuracy. The versatile 3-operational amplifier design, small size, and low power make it ideal for a wide range of portable applications.
The purpose of the component is to amplify the ECG signals coming from the electrodes.

Main features

- Low Offset Voltage: 25 uV (Maximum)
- Low Input Bias Current: 200 pA (Maximum)
- Supply Range: 1.8 V to 5.5 V
- Input Voltage: (V–) +0.1 V to (V+) –0.1 V
- Low Quiescent Current: 50 uA
- Operating Temperature: –40°C to +125°C

Pinout and package

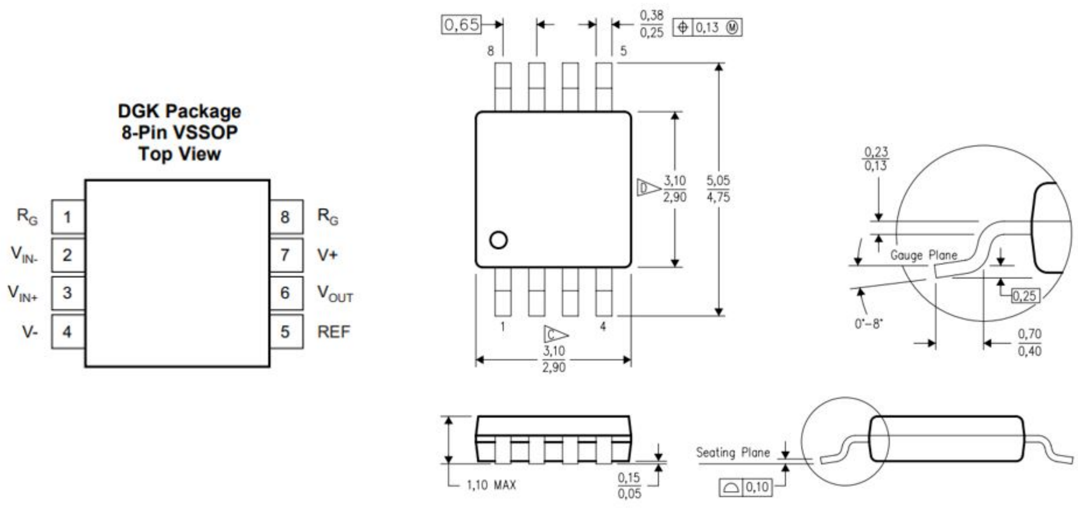


Figure 5.23: INA333 pinout and package

Schematic

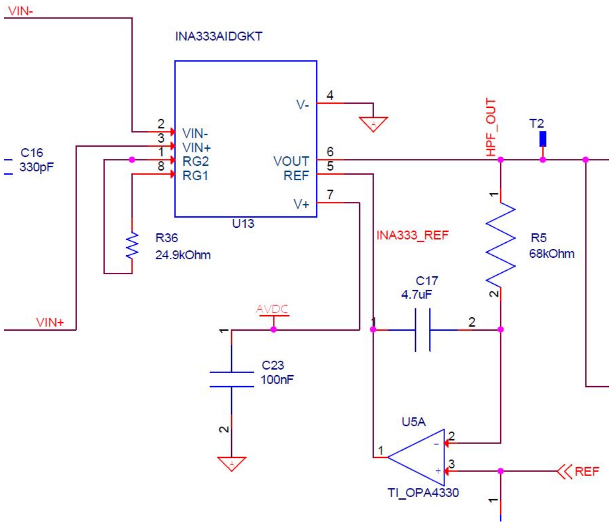


Figure 5.24: INA333 schematic

5.1.10 Amplifier OPA4330

The OPA330 [21] series of CMOS operational amplifiers offer precision performance at a very competitive price. It is used for signal elaboration inside the front end ecg section.

Main features

- Low Offset Voltage: 50 uV (Maximum)
- Quiescent Current: 35 uA (Maximum)
- Supply Voltage: 1.8 V to 5.5 V

Pinout and package

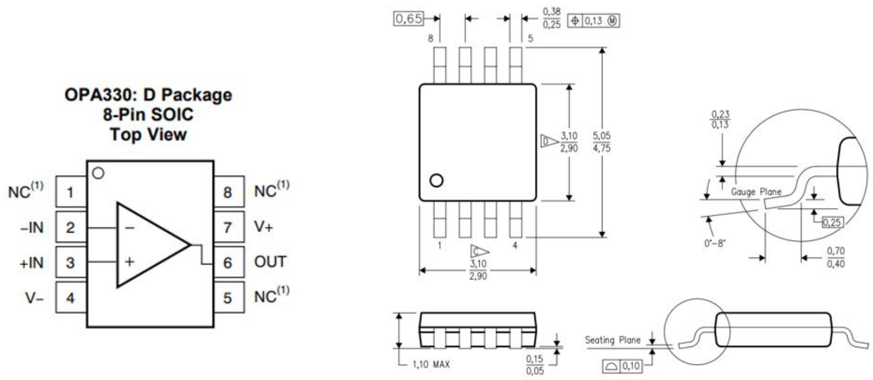


Figure 5.25: OPA4330 pinout and package

Schematic

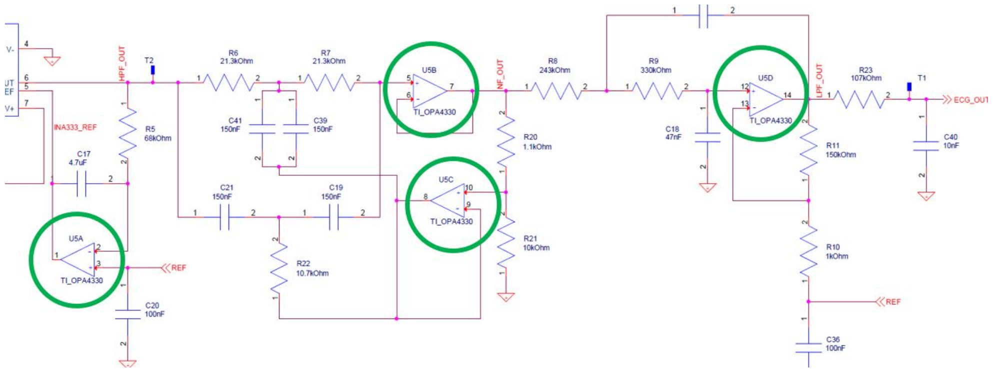


Figure 5.26: OPA4330 schematic

5.1.11 REF2033

The REF2033 [22] provides a reference voltage for the ADC and a second highly-accurate voltage that can be used to bias the input bipolar signals. Applications with only a positive supply voltage often require additional stable voltage in the middle of the analog-to-digital converter input range to bias input bipolar signals.

Pinout and package

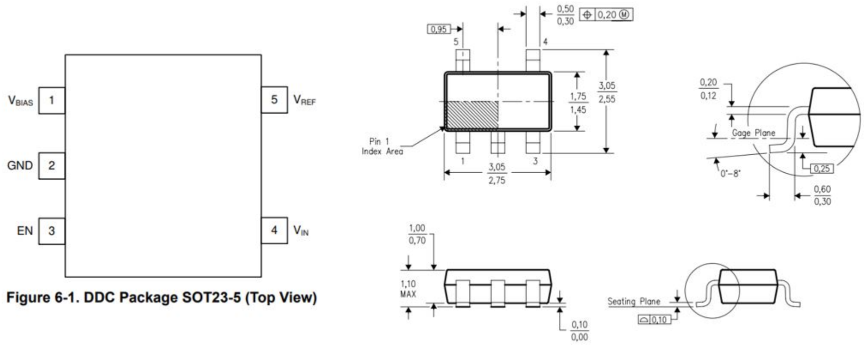


Figure 5.27: REF2033 pinout and package

Schematic

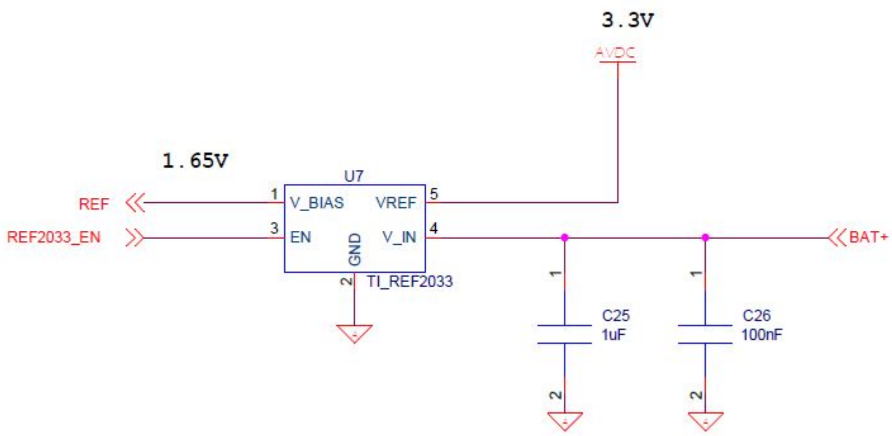


Figure 5.28: REF2033 schematic

5.1.12 Mosfet

Mosfet TPS22924BYZZR [23] is part of the power management section. It doesn't allow the functioning of the watch in case the USB presence. During charge, the smartwatch can't be used by the user for healt monitoring. The mosfet cut the supply. It was chosen for its compact size, since it was already known that it would be placed in a very dense component area of the board.

Figure 5.29: Mosfet model TPS22924BYZZR

Pinout and package

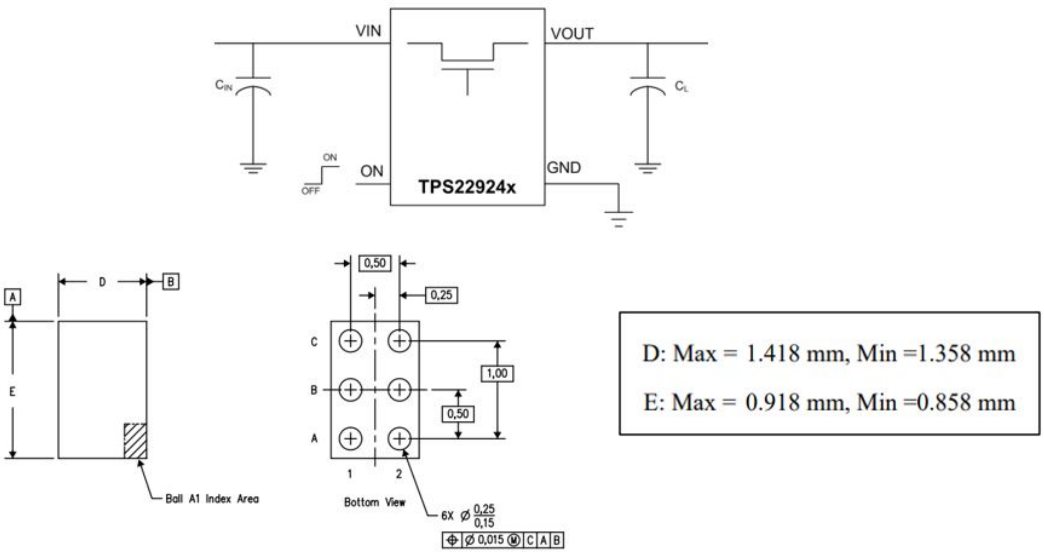


Figure 5.30: Mosfet TPS22924BYZZR pinout and dimensions

Schematic

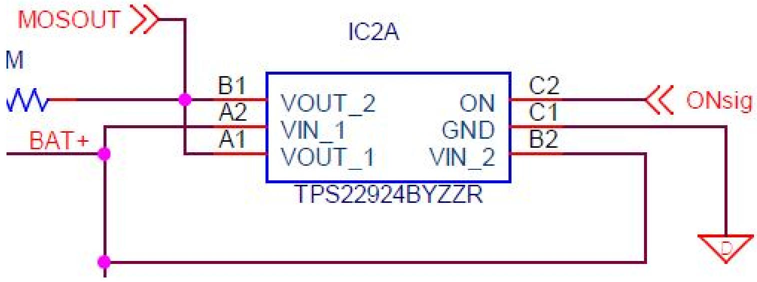
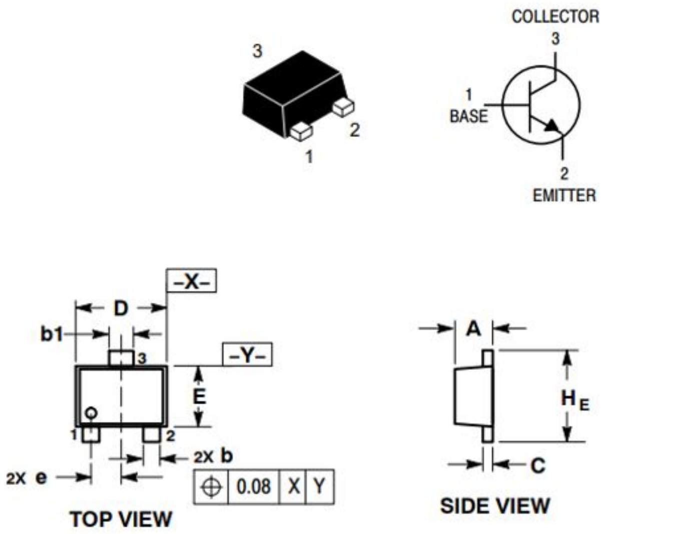


Figure 5.31: Mosfet TPS22924BYZZR schematic

5.1.13 BJT

BJT MMBT2222AM3T5G [24] has the only scope to switch off the mosfet, in order to cut the supply at the board. Choice of the component driven by the availability of the market.

Pinout and package



DIM	MILLIMETERS MIN	NOM	MAX
A	0.45	0.50	0.55
b	0.15	0.21	0.27
b1	0.25	0.31	0.37
C	0.07	0.12	0.17
D	1.15	1.20	1.25
E	0.75	0.80	0.85
e		0.40 BSC	
H_E	1.15	1.20	1.25
L		0.29 REF	
L2	0.15	0.20	0.25

Figure 5.32: BJT MMBT2222AM3T5G pinout and dimensions

Schematic

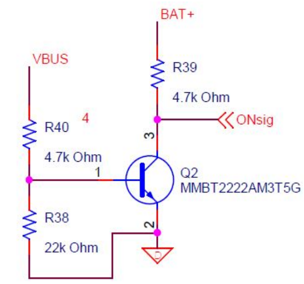


Figure 5.33: BJT MMBT2222AM3T5G schematic

5.1.14 micro-USB port

Micro-USB port Molex 105164-0001 [25] is used exclusively for recharge the battery. The option to flash new firmware version inside the microcontroller through this port is not supported. This last task is in charge of the JTAG connector.

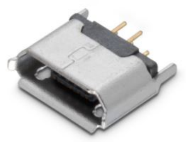


Figure 5.34: microUSB port

Schematic

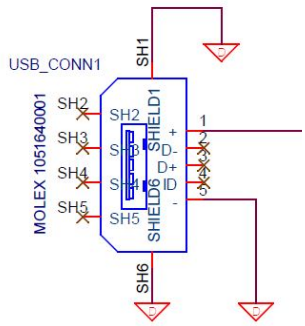


Figure 5.35: Micro-USB schematic

5.1.15 New JTAG interface

The new JTAG interface remove the old connector instead of six simple through holes, in order to reduce the height of the board. Another board, named JTAG board, convert this new interface into the classic JTAG connection used by the T.I. launchpad.

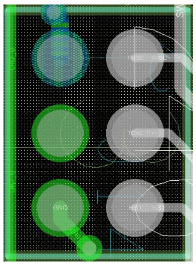


Figure 5.36: JTAG interface

Schematic

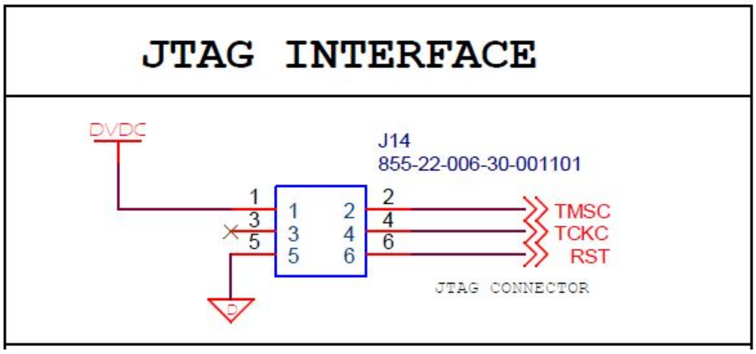


Figure 5.37: JTAG schematic

5.1.16 ECG and Battery connectors

Simple two pin female connectors SM02B-SRSS-TB [26], one for the battery ground and supply, the other one for the ECG signals of the two electrodes.

Figure 5.38: Battery connector

Schematic

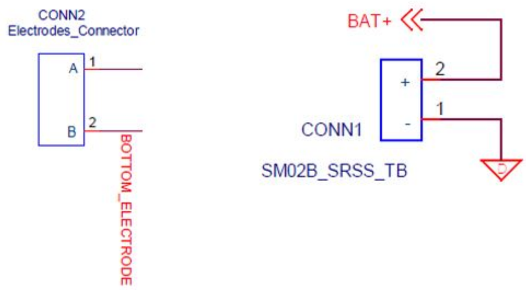


Figure 5.39: Connectors SM02B-SRSS-TB schematic

5.1.17 FFC connector

Wurth Elektronik 687108149022 [27] is used for PPG board interface.

Figure 5.40: Wurth Elektronik 687108149022

Dimensions

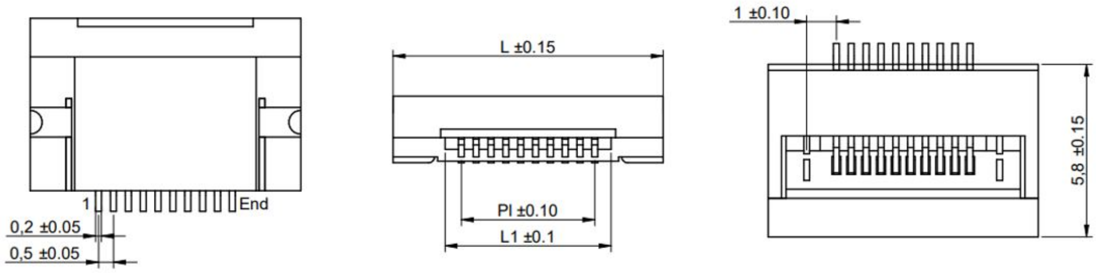


Figure 5.41: Wurth Elektronik 687108149022 dimensions

Schematic

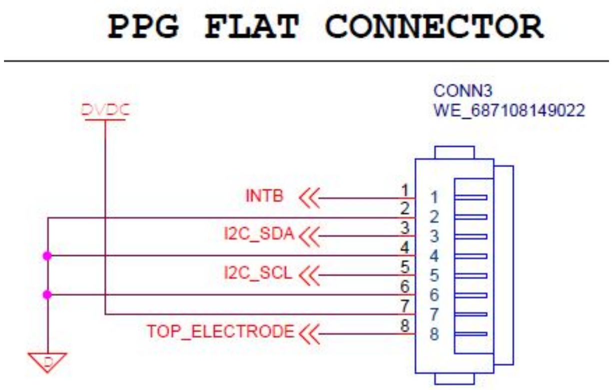


Figure 5.42: Wurth Elektronik 687108149022 schematics

5.1.18 Board to board connector

Figure 5.43: Connector MOLEX 505413-0610

Connector MOLEX 505413-0610 [28] in order to embed the temperature board. The connector was chosen because he has as the minimum height so as not to increase the thickness of the watch too much. It is also a SMD component, so it stays only in one layer minimizing the space. It has pin for 4 signals: VDD, GND, SDA and SCL.

Schematic

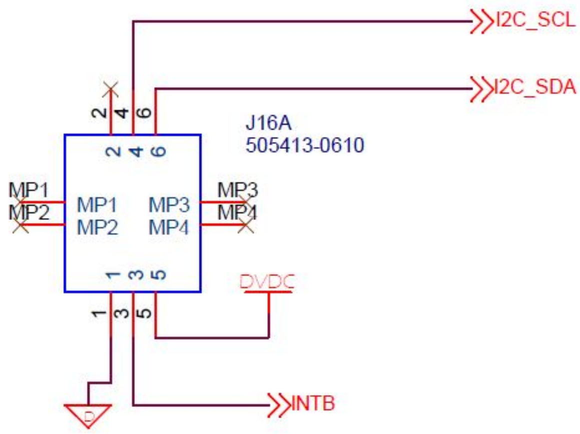


Figure 5.44: MOLEX 505413-0610 schematic

5.1.19 Push button

Push button EVQ-PUB02K [29] has the task to wake up the microcontroller when it is in sleep mode. When the smartwatch is not used and the microcontroller goes in sleep mode, the user must press the push button in order to perform a ECG measurement. Push button on the previous board it was smaller than the one. It was not so sensitive to the user, so for this new development it was used a push button of one size larger.

Figure 5.45: Push button model EVQ-PUB02K

Schematic

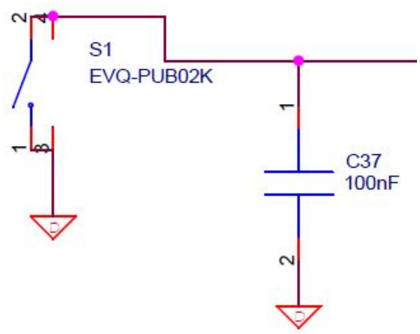


Figure 5.46: Push button EVQ-PUB02K schematic

5.1.20 Battery switch

The battery switch Wurth 450405020524 [30] is the most crucial component that can maximize the life of the battery. Switch can disconnect totally the battery to the rest of the circuit. The choice fell on a smd component, which can be small but protruding to be user sensitive.

Figure 5.47: Battery switch model Wurth Elektronik 450405020524

Schematic

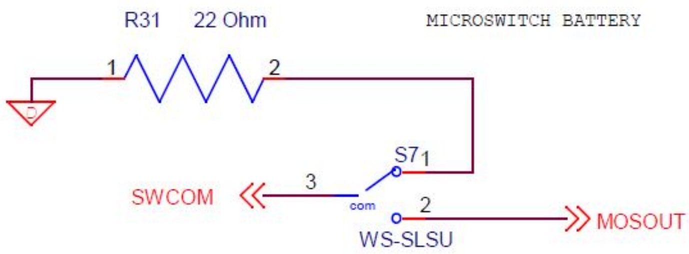


Figure 5.48: Switch wurth 450405020524 schematic

5.1.21 Leds

Inside ECG board there are two leds: one red (SML-P11UTT86R [31]) and one green (SML-P13PTT86R [32]). The red one is on when the smartwatch is in charge mode. The green led is driven by the microcontroller when the watch is on.

Figure 5.49: Led red model SML-P11UTT86R and green led model SML-P13PTT86R

Schematic

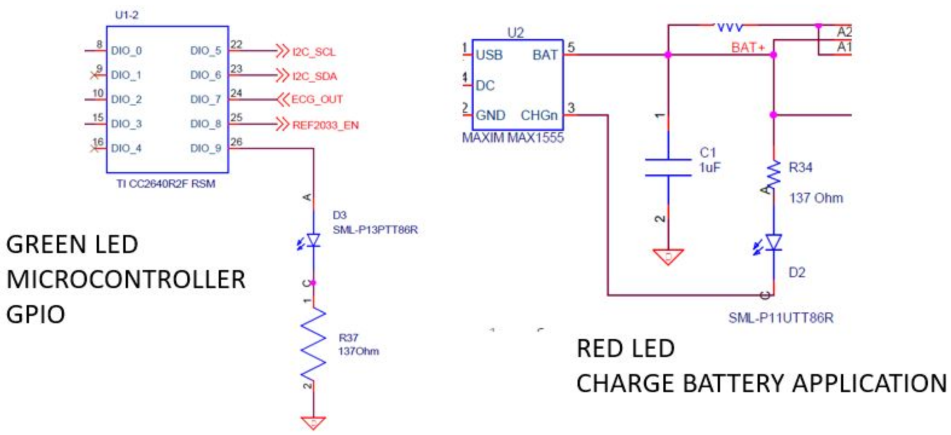


Figure 5.50: Led schematics

5.1.22 Crystal and oscillators

Oscillator of 32kHz and 24MHz needed for the correct functioning and supply of the microcontroller.

32kHz oscillator

Dimensions and schematic [33].

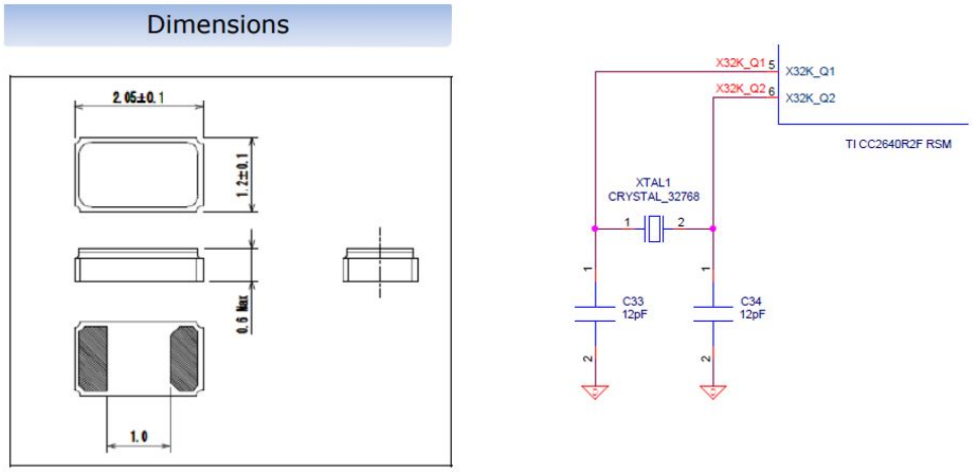


Figure 5.51: SC20S-12.5PF20PPM schematics

24MHz oscillator

Dimensions and schematic [34].

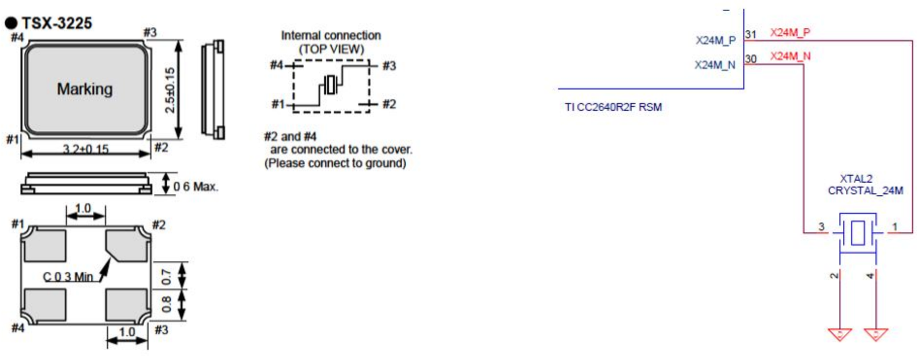


Figure 5.52: TSX-3225 24.0000MF20X-B schematics

5.2 PPG board

5.2.1 SpO2 sensor MAX86161

Figure 5.53: MAX86161 SpO2 sensor

Description

The MAXM86161 [35] is an ultra-low-power optical data acquisition system. On the transmitter side, the MAXM86161 has three programmable high-current LED drivers. On the receiver side, MAXM86161 consists of a high efficiency PIN photo-diode and an optical readout channel. The LED current DACs have 8 bits of dynamic range with four programmable full-scale ranges of 31mA, 62mA, 94mA, and 124mA. The LED pulse width can be programmed from 14.8us to 117.3us to allow the algorithms to optimize the accuracy.
The component, already present on PulsECG, was also confirmed in this project as it provides excellent results.

Main features

- Operating voltage limits: from 3.0V to 5.5V
- -40°C to +85°C Operating Temperature Range
- High-Resolution 19-bit Charge Integrating ADC

Pinout and package

Package information: 4.3mm(D) x 2.9mm (E) x 1.4mm 14-Pin OLGA.

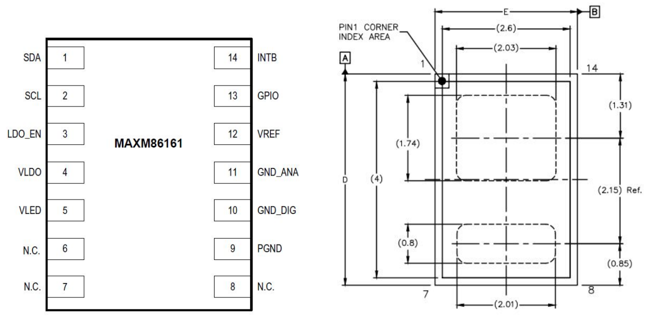


Figure 5.54: MAX86161 pinout

Schematic

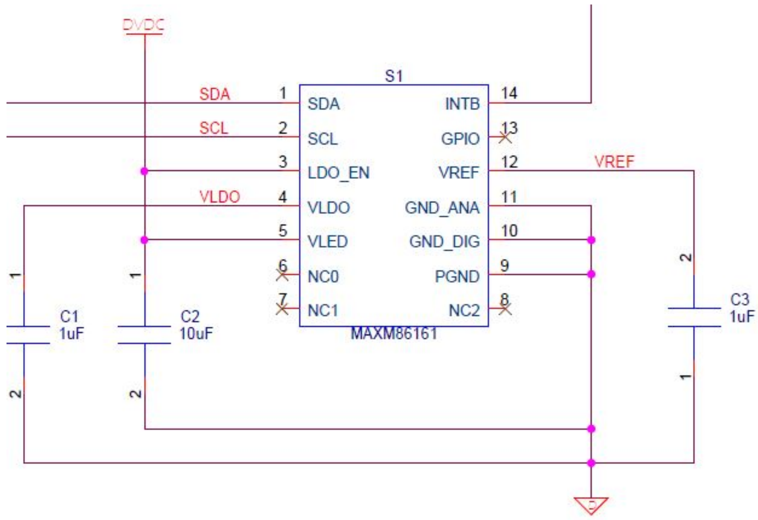


Figure 5.55: MAXM86161 schematics

5.2.2 Flash memory unit W25N01GV

Figure 5.56: W25N01GV - Flash memory chip

Description

The W25N01GV (1G-bit) Serial SLC NAND Flash Memory [36] provides a storage solution for systems with limited space, pins and power. The W25N SpiFlash family incorporates the popular SPI interface and the traditional large NAND non-volatile memory space. They are ideal for code shadowing to RAM, executing code directly from Dual/Quad SPI (XIP) and storing voice, text and data. The flash memory with the smallest 1GB memory available at the time of selection was chosen.

Main features

- Capacity: 1G-bit
- Power supply: 2.7V to 3.6V
- Consumption: 25mA active, 10uA standby current
- Operating temperature: -40°C to +85°C
- Communication protocol: SPI
- More than 100,000 program cycles and 10-year data retention

Pinout and package

Package information: 8-pad WSON, 8mm (D) x 6mm (E)

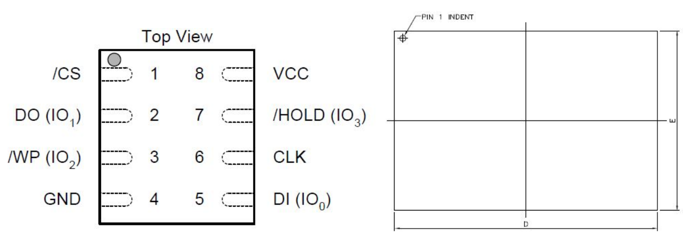


Figure 5.57: W25N01GV pinout and dimensions

Schematic

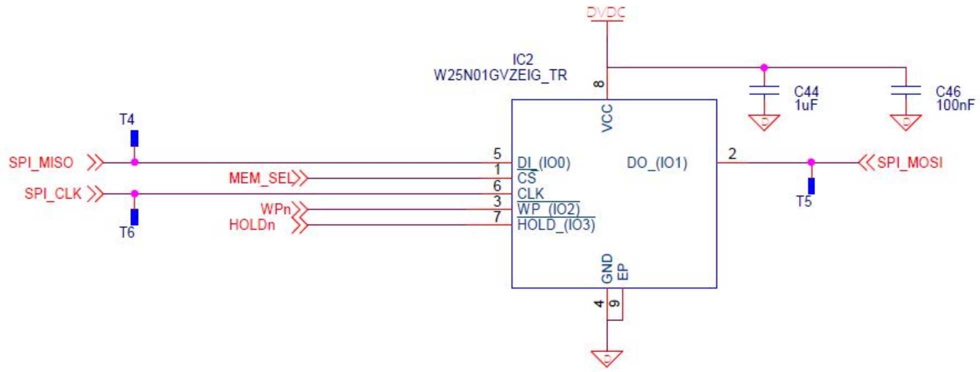


Figure 5.58: W25N01GV schematics

5.2.3 SPI to I2C interface

Figure 5.59: SC18IS602B - SPI to I2C interface

Description

The I2C to SPI interface is needed to link the flash memory with the rest of the watch. The watch and in particular the mmicrocontroller was designed to wirk with I2C communication, but the memory works with SPI protocol. The SC18IS602B [37] operates as an I2C-bus slave-transmitter or slave-receiver and an SPI master.

Pinout and package

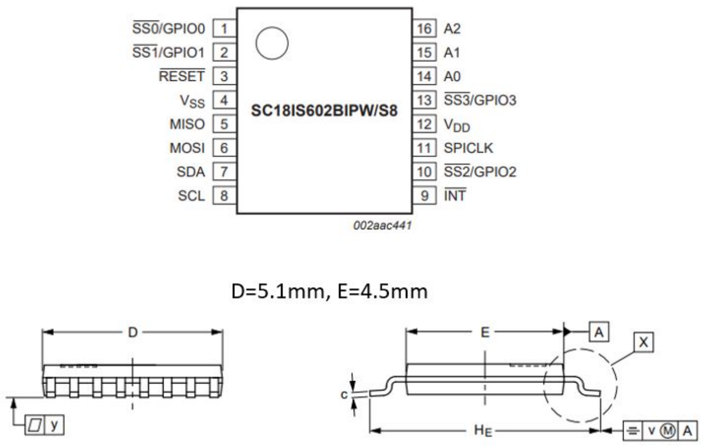


Figure 5.60: SC18IS602BIPW/S8HP - i2c to spi pinout aand package

Schematic

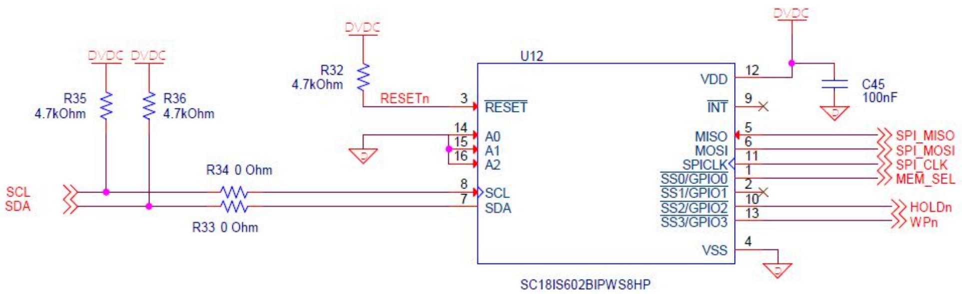


Figure 5.61: SC18IS602BIPW schematics

5.3 Temperature board

5.3.1 Human Body Temperature Sensor - MAX30205

Figure 5.62: MAX30205 - Human body temperature sensor

Description

The MAX30205 temperature sensor [38] accurately measures temperature and can provide an overtemperature alarm output. Accuracy meets clinical thermometry specification of the ASTM E1112 when soldered on the final PCB. Communication is through an I2C-compatible, 2-wire serial interface.
This sensor was chosen because it is suitable for taking clinical measurements, a specification critical to the purpose of the watch. Tests performed with its evaluation board showed good accuracy in measuring body temperatures.

Main features

- 0.1°C Accuracy (37°C to 39°C)
- 16-Bit (0.00390625°C) Temperature Resolution
- 2.7V to 3.3V Supply Voltage Range
- 600uA (typ) Operating Supply Current

Pinout and package

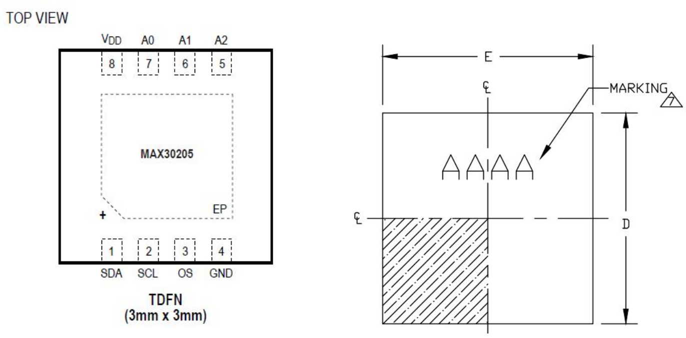


Figure 5.63: MAX30205 pinout and dimensions

Schematic

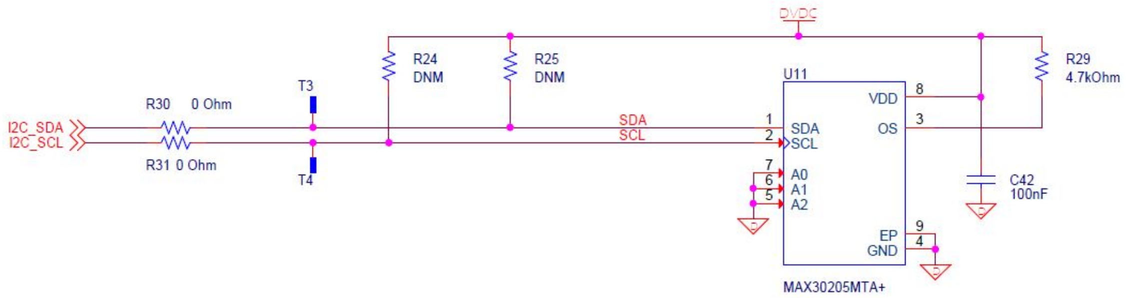


Figure 5.64: MAX30205 schematics

5.3.2 Board to board connector

Figure 5.65: Connector MOLEX 505417-0610

Connector MOLEX 505417-0610 [39] in order to embed the temperature board with the ECG board. The connector was chosen because he has as the minimum height so as not to increase the thickness of the watch too much. It is also a SMD component, so it stays only in one layer minimizing the space. It has pin for 4 signals: VDD, GND, SDA and SCL.

Schematic

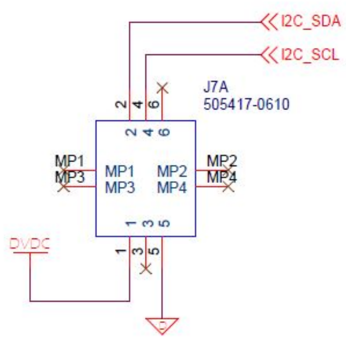


Figure 5.66: MOLEX 505417-0610 schematics

5.4 JTAG board

5.4.1 JTAG to launchpad connector

The JTAG Connector FTSH-105-01-L-D-K [40] is used to connect the microcontroller to the PC in order to program the processor and also debug it.

Figure 5.67: JTAG Connector FTSH-105-01-L-D-K

Schematic

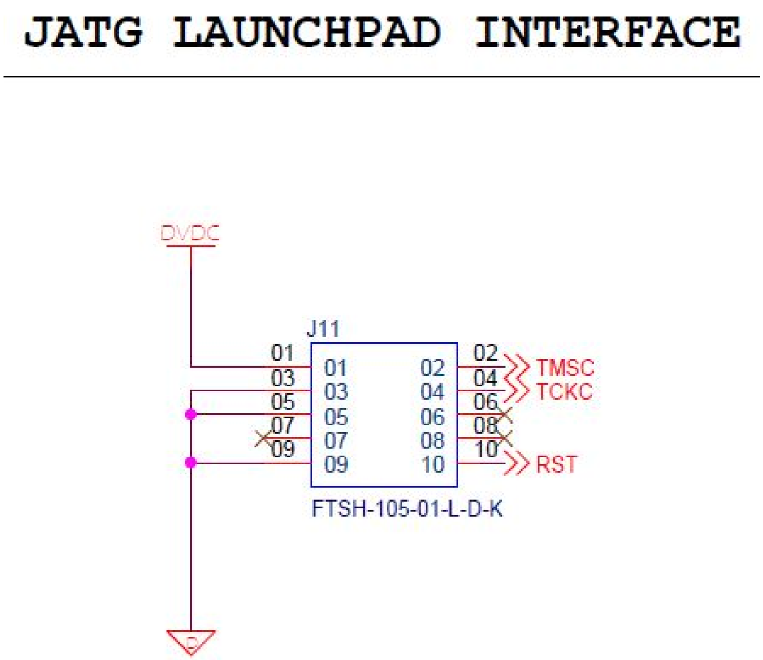


Figure 5.68: JTAG Connector FTSH-105-01-L-D-K schematics

5.4.2 JTAG to ECG board connector

JATG connector MILL MAX 855-22-006-30-001101 [41].

Figure 5.69: Mill-Max 855-22-006-30-001101

Schematic

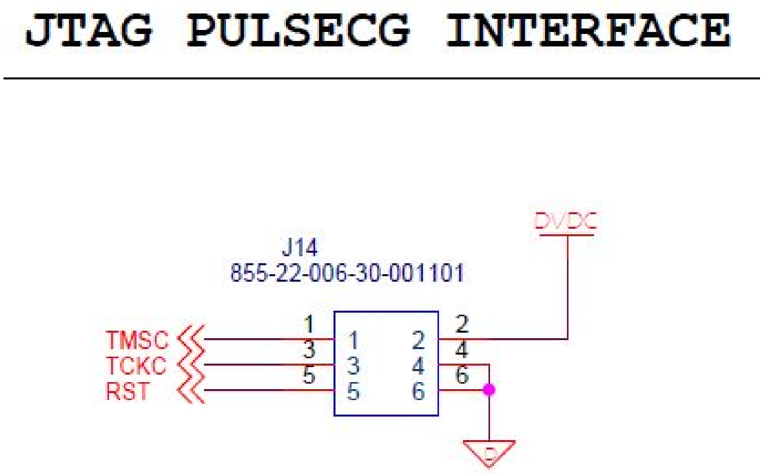


Figure 5.70: Mill-Max 855-22-006-30-001101 schematics

CHAPTER 6

ECGWATCH: hardware implementation

The new ECGwatch should be viewed as a derivative of PulsECG, as much of its structure is retained, including:

- The microcontroller
- The section of analogic front-end
- The new features about the power management section
- The new JTAG interface

Instead, they are eliminated as unused functionality:

- The connector for PPG board
- The accelerometer
- The connector for temperature board

CHAPTER 7

Bill Of Materials

7.1 BOM ECG board

Accelerometer **and** temperature board connector Revised: Friday, June 17, 2022
Reineri Matteo – PulsECG Revision: 00

Bill **Of** Materials June 18,2022 21:56:29 Page1

Item	Quantity	Reference	Value	Part Number	COST(e)
1	1	A1		TI AN043	N.A.
2	2	CONN1, CONN2		SM02B_SRSS_TB	0.90
3	1	CONN3		WE_687108149022	0.96
4	5	C1, C2, C25, C27, C43	1uF	CL05B105KQ5QNWC	0.95
5	1	C3	330nF	JMK105BJ334KV–F	0.11
6	4	C4, C5, C6, C12	10uF	GRM155R60J106ME15D	0.72
7	15	C7, C8, C9, C10, C11, C13, C20, C23, C24, C26, C28, C35, C36, C37, C38	100nF	C0402C104K9RACTU	0.87
8	2	C14, C15	33pF	C0402C330F3GACTU	2.90
9	1	C16	330pF	C0402H331J3GACTU	0.97
10	1	C17	4.7uF	C1005JB1A475K050BC	0.47
11	1	C18	47nF	GRM155R71E473JA88D	0.14
12	4	C19, C21, C39, C41	150nF	C1005X7R1A154K050BB	0.44
13	1	C22	680pF	C0402C681J3GACTU	0.29
14	2	C29, C30	1.2pF	C0402C129B5GACAUTO	0.52
15	3	C31, C33, C34	12pF	VJ0402A120JXQCW1BC	0.57
16	2	C32, R35	DNM		N.A.
17	1	C40	10nF	GRM1555C1E103JE01J	0.23
18	1	D2		SML–P11UTT86R	0.37
19	1	D3		SML–P13PTT86R	0.39
20	1	F1		BLM18HE152SN1	0.20
21	1	IC1		MXC6655XA	1.65
22	1	IC2A		TPS22924BYZZR	0.93

23	1	J14		855−22−006−30−001101	N.A
24	1	J16A		505413−0610	0.62
25	1	L1	10nH	7447840110G	0.10
26	1	L3	15nH	PE−0402CL150JTT	0.10
27	1	L4	2nH	7447840020G	0.10
28	1	Q2		MMBT2222AM3T5G	0.22
29	3	R1,R2,R16	100kOhm	MCS04020D1003BE000	1.26
30	1	R5	68kOhm	MCS04020C6802FE000	0.14
31	2	R6,R7	21.3kOhm	RN73H1ETTP2132D25	1.00
32	1	R8	243kOhm	RP73PF1E243KBTD	0.59
33	1	R9	330kOhm	MCS04020C3303FE000	0.50
34	1	R10	1kOhm	ERA−2VEB1001X	0.55
35	1	R11	150kOhm	CPF0402B150KE1	0.57
36	3	R15,R18,R19	3.3kOhm	TNPW04023K30BEED	1.92
37	1	R17	0Ohm	SFR01MZPJ000	0.11
38	1	R20	1.1kOhm	ERA−2AEB112X	0.34
39	1	R21	10kOhm	RN73C1E10KBTD	0.76
40	1	R22	10.7kOhm	ERA−2ARB1072X	0.78
41	1	R23	107kOhm	RT0402BRD07107KL	0.50
42	1	R30	2.7kOhm	ERA−2ARB272X	0.77
43	1	R31	22 Ohm	ESR01MZPJ220	0.25
44	1	R34	137 Ohm	TNPW0402137RBEED	0.64
45	1	R36	24.9kOhm	SFR01MZPF2492	0.11
46	1	R37	137Ohm	TNPW0402137RBEED	0.64
47	1	R38	22k Ohm	ERA−2AED223X	0.21
48	2	R39,R40	4.7k Ohm	MCS04020D4701BE000	1.02
49	1	S1		EVQ−PUB02K	0.58
50	1	S7	WS−SLSU	450405020524	0.97
51	2	T1,T2		TE RCU−0C	0.40
52	1	USB_CONN1		MOLEX 1051640001	0.97
53	1	U1		TI CC2640R2F RSM	4.81
54	1	U2		MAXIM MAX1555	2.35
55	1	U3		MAXIM MAX1759	6.19
56	1	U5		TI_OPA4330	4.49
57	1	U7		TI_REF2033	5.73
58	1	U8		DVIULC6−2x6_ESD_PROT.	1.00
59	1	U9		MAXIM MAX17048	2.97
60	1	U13		INA333AIDGKT	6.28
61	1	XTAL1		CRYSTAL_32768	0.74
62	1	XTAL2		CRYSTAL_24M	0.79
				TOTAL:	66.67

Table 7.1: ECG board: BOM and cost

7.2 BOM PPG board

```
PPG   Revised: Thursday, December 02, 2021
Reineri Matteo - PulsEGC PPG            Revision: 01

Bill Of Materials          December 30,2021       12:26:29   Page1
Item    Quantity           Reference         Value     Part                      Cost(e)
-----------------------------------------------------------------------------------

1       1                  CONN1                       WE_687108149022           0.96
2       1                  CONN2                       Electode_connector_PPG    N.A.
3       3                  C1,C3,C44         1uF       CL05B105KQ5QNWC           0.57
4       1                  C2                10uF      GRM155R60J106ME15D        0.18
5       2                  C45,C46           100nF     C0402C104K9RACTU          0.2
6       1                  IC2                         W25N01GVZEIG_TR           3,16
7       1                  R1                10kOhm    RN73C1E10KBTD             0.76
8       3                  R32,R35,R36       4.7kOhm   SFR01MZPJ472              1.53
9       2                  R33,R34           0 Ohm     SFR01MZPJ000              0.22
10      1                  S1                          MAXM86161                 10.24
11      6                  T1,T2,T3,                   TE RCU-0C                 1.2
                           T4,T5,T6
12      1                  U12                         SC18IS602BIPWS8HP         4.53
-----------------------------------------------------------------------------------
                                                                     TOTAL:     23.55
```

Table 7.2: PPG board: BOM and cost

7.3 BOM temperature board

TEMPERATURE SENSOR BOARD Revised: Saturday, June 18, 2022
Reineri Matteo – PulsEGC Revision: 01

Bill **Of** Materials June 18,2022 21:55:29 Page1

Item	Quantity	Reference	Value	Part	Cost(E)
1	1	C42	100nF	C0402C104K9RACTU	0.1
2	1	J7A		505417−0610	0.62
3	2	R24, R25	DNM		N.A.
4	1	R29	4.7kOhm	SFR01MZPJ472	0.51
5	2	R30, R31	0 Ohm	SFR01MZPJ000	0.22
6	2	T3, T4		TE RCU–0C	0.4
7	1	U11		MAX30205MTA+	5.13
				TOTAL:	6.98

Table 7.3: Temperature board: BOM and cost

7.4 BOM ECGWATCH

Analog Front **End** Revised: Tuesday, May 17, 2022
Reineri Matteo – ECGwatch Revision: 02

Bill **Of** Materials June 18,2022 22:05:20 Page1

Item	Quantity	Reference	Value	Part	Cost(e)
1	1	A1		TI AN043	N.A.
2	2	CONN1, CONN2		SM02B_SRSS_TB	0.90
3	4	C1, C2, C25, C27	1uF	CL05B105KQ5QNWC	0.95
4	1	C3	330nF	JMK105BJ334KV–F	0.11
5	4	C4, C5, C6, C12	10uF	GRM155R60J106ME15D	0.72
6	15	C7, C8, C9, C10, C11, C13, C20, C23, C24, C36, C26, C28, C35, C37, C38	100nF	C0402C104K9RACTU	0.87
7	2	C14, C15	33pF	C0402C330F3GACTU	2.9
8	1	C16	330pF	C0402H331J3GACTU	0.97
9	1	C17	4.7uF	C1005JB1A475K050BC	0.47
10	1	C18	47nF	GRM155R71E473JA88D	0.14
11	4	C19, C21, C39, C41	150nF	C1005X7R1A154K050BB	0.44
12	1	C22	680pF	C0402C681J3GACTU	0.29
13	2	C29, C30	1.2pF	C0402C129B5GACAUTO	0.52

14	3	C31, C33, C34	12pF	VJ0402A120JXQCW1BC	0.57
15	2	C32, R35	DNM	N.A.	
16	1	C40	10nF	GRM1555C1E103JE01J	0.23
17	1	D2		SML–P11UTT86R	0.37
18	1	D3		SML–P13PTT86R	0.39
19	1	F1		MURATA BLM18HE152SN1	0.20
20	1	IC1A		TPS22924BYZZR	0.93
21	1	J14		855−22−006−30−001101	N.A.
22	1	L1	10nH	7447840110G	0.1
23	1	L3	15nH	PE–0402CL150JTT	0.1
24	1	L4	2nH	7447840020G	0.1
25	1	Q2		MMBT2222AM3T5G	0.22
26	3	R1, R2, R16	100kOhm	MCS04020D1003BE000	1.26
27	1	R3	24.9kOhm	SFR01MZPF2492	0.11
28	1	R5	68kOhm	MCS04020C6802FE000	0.14
29	2	R6, R7	21.3kOhm	RN73H1ETTP2132D25	1.00
30	1	R8	243kOhm	RP73PF1E243KBTD	0.59
31	1	R9	330kOhm	MCS04020C3303FE000	0.50
32	3	R10, R18, R19	1kOhm	ERA–2VEB1001X	1.65
33	1	R11	150kOhm	CPF0402B150KE1	0.57
34	1	R15	3.3kOhm	TNPW04023K30BEED	0.64
35	1	R17	0Ohm	SFR01MZPJ000	0.11
36	1	R20	1.1kOhm	ERA–2AEB112X	0.34
37	1	R21	10kOhm	RN73C1E10KBTD	0.76
38	1	R22	10.7kOhm	ERA–2ARB1072X	0.78
39	1	R23	107kOhm	RT0402BRD07107KL	0.50
40	1	R31	22 Ohm	ESR01MZPJ220	0.25
41	2	R34, R36	137 Ohm	TNPW0402137RBEED	0.64
42	2	R37, R39	4.7k Ohm	MCS04020D4701BE000	1.02
43	1	R38	22k Ohm	ERA–2AED223X	0.21
44	1	S1		EVQ–PUB02K	0.58
45	1	S7	WS–SLSU	450405020524	0.97
46	2	T1, T2		TE RCU–0C	0.40
47	1	USB_CONN1		MOLEX 1051640001	0.97
48	1	U1		TI CC2640R2F RSM	4.81
49	1	U2		MAXIM MAX1555	2.35
50	1	U3		MAXIM MAX1759	6.19
51	1	U4		TI_INA333	6.28
52	1	U5		TI_OPA4330	4.49
53	1	U7		TI_REF2033	5.73
54	1	U8		DVIULC6–2x6_ESD_PROT.	1.00
55	1	U9		MAXIM MAX17048	2.97
56	1	XTAL1		CRYSTAL_32768	0.74
57	1	XTAL2		CRYSTAL_24M	0.79
				TOTAL:	63.43

Table 7.4: ECGWatch: BOM and cost

CHAPTER 8

Schematics

The design of the new PulsECG is divided in four different projects, one for each board that make up the watch: ECG board, PPG board, TEMP board and JTAG board. Each project has a number of sheets that depends by the architecture inside the specific board.

8.1 ECG board schematics

- POWER MANAGEMENT: it contains the battery recharge schematics, supply regulation and decoupling section.
- MICROCONTROLLER: this sheet shows the connection of the microcontroller to the power supply, oscillators and the bluetooth antenna.
- MICROCONTROLLER DIOs: it is focused on the digital input/output pins of the microcontroller (JTAG, push button and led) and the pinout for the board 2 conntection.
- ACCELEROMETER AND TEMPERATURE: here there are the schematics of the new sensor added in this project and the connector for the tempearture board.
- ANALOG FRONT END: about the acquisition and filtering of the ECG signals.

8.1.1 ECG board: analog front-end section

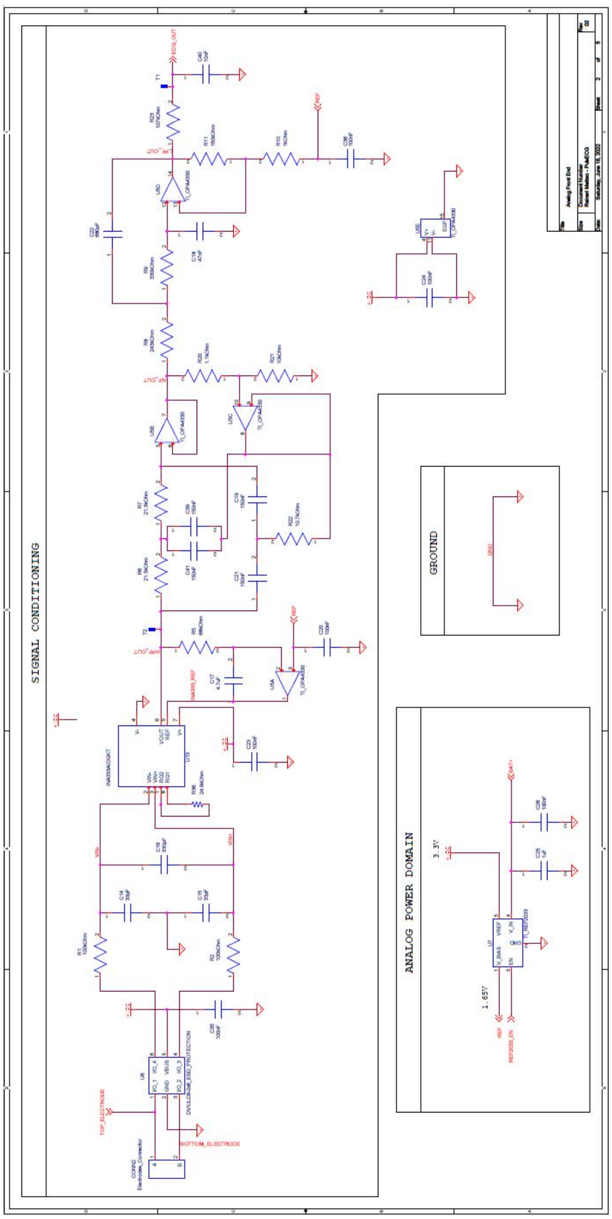


Figure 8.1: ECG board: analog front-end schematic

8.1.2 ECG board: microcontroller section

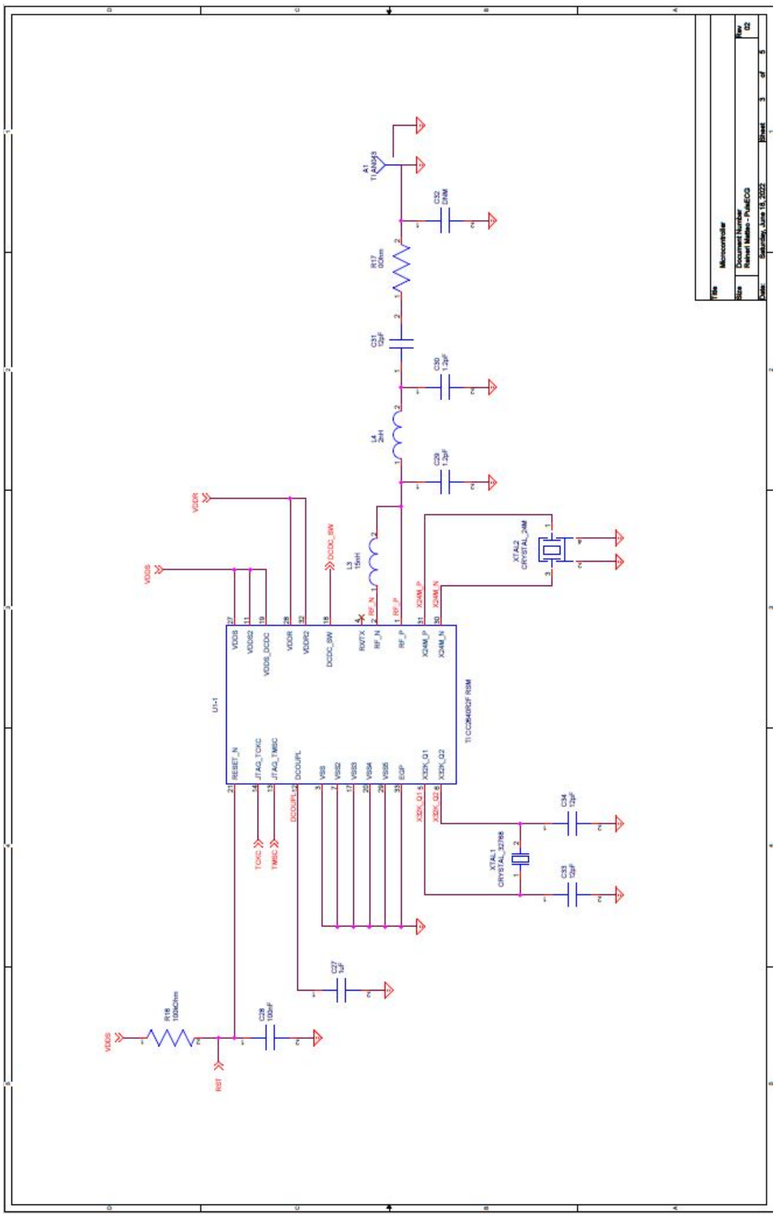


Figure 8.2: ECG board: microcontroller schematic

8.1.3 ECG board: microcontroller DIOs section

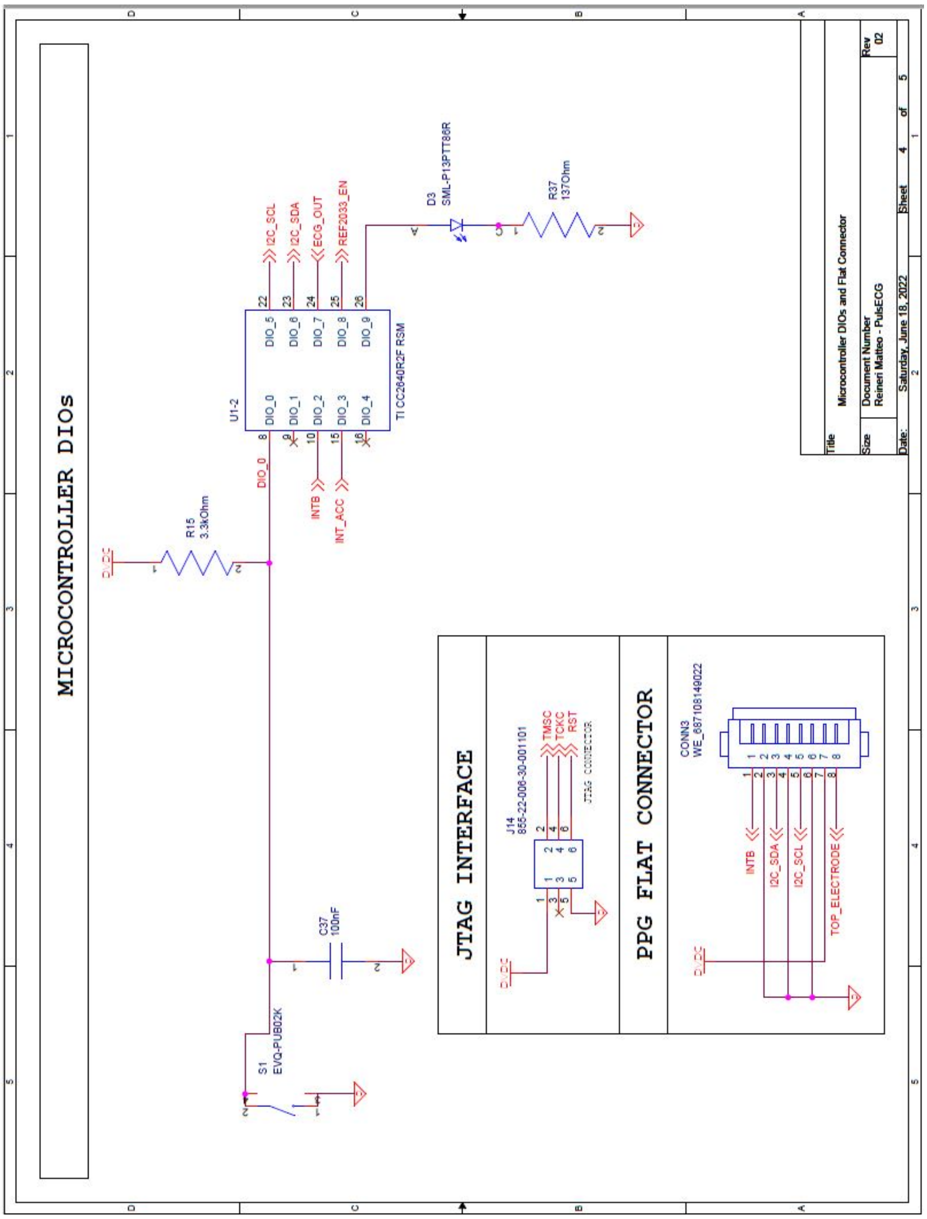


Figure 8.3: ECG board: microcontroller DIOs schematic

8.1.4 ECG board: power management section

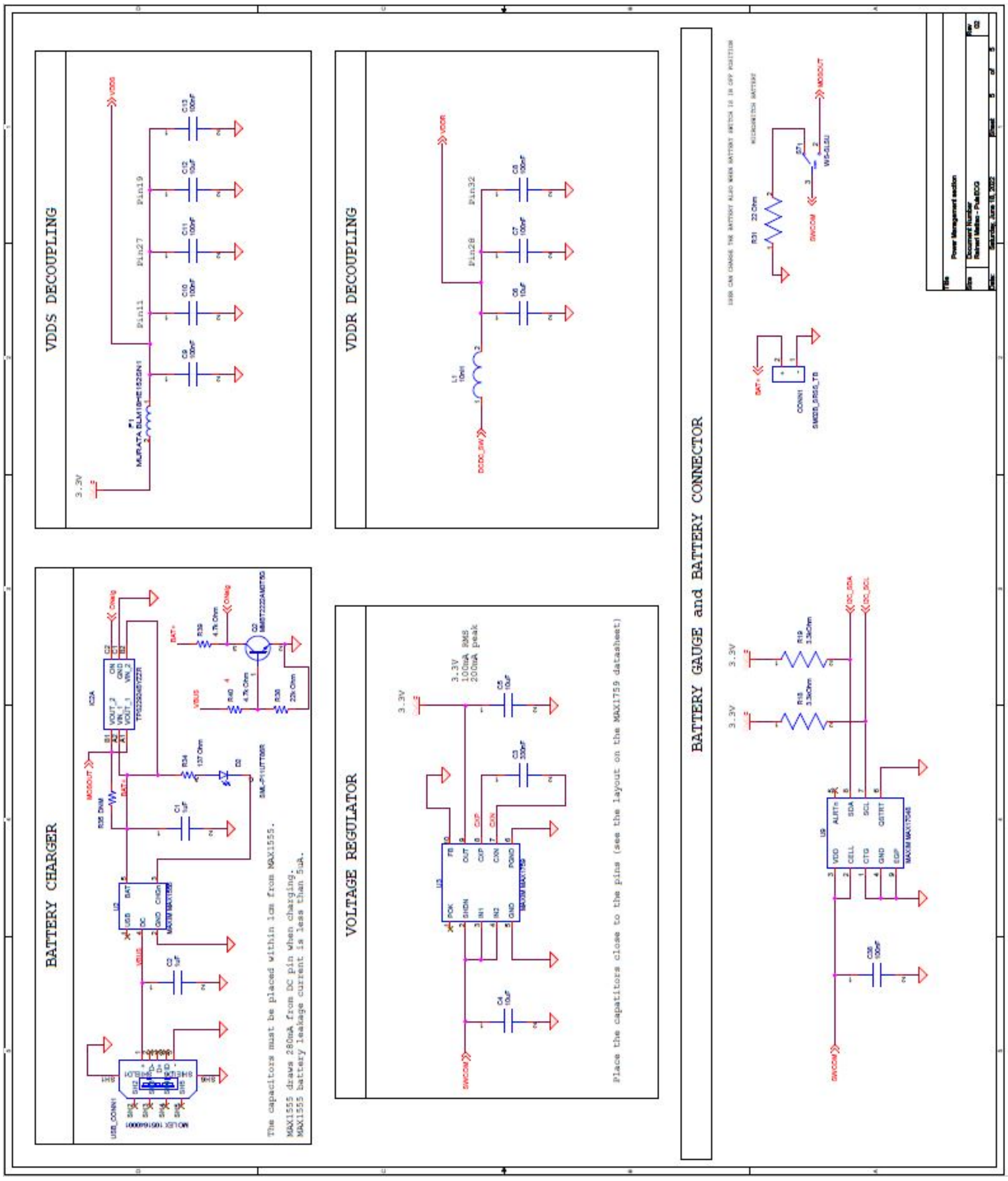


Figure 8.4: ECG board: power management schematic

8.1.5 ECG board: accelerometer section

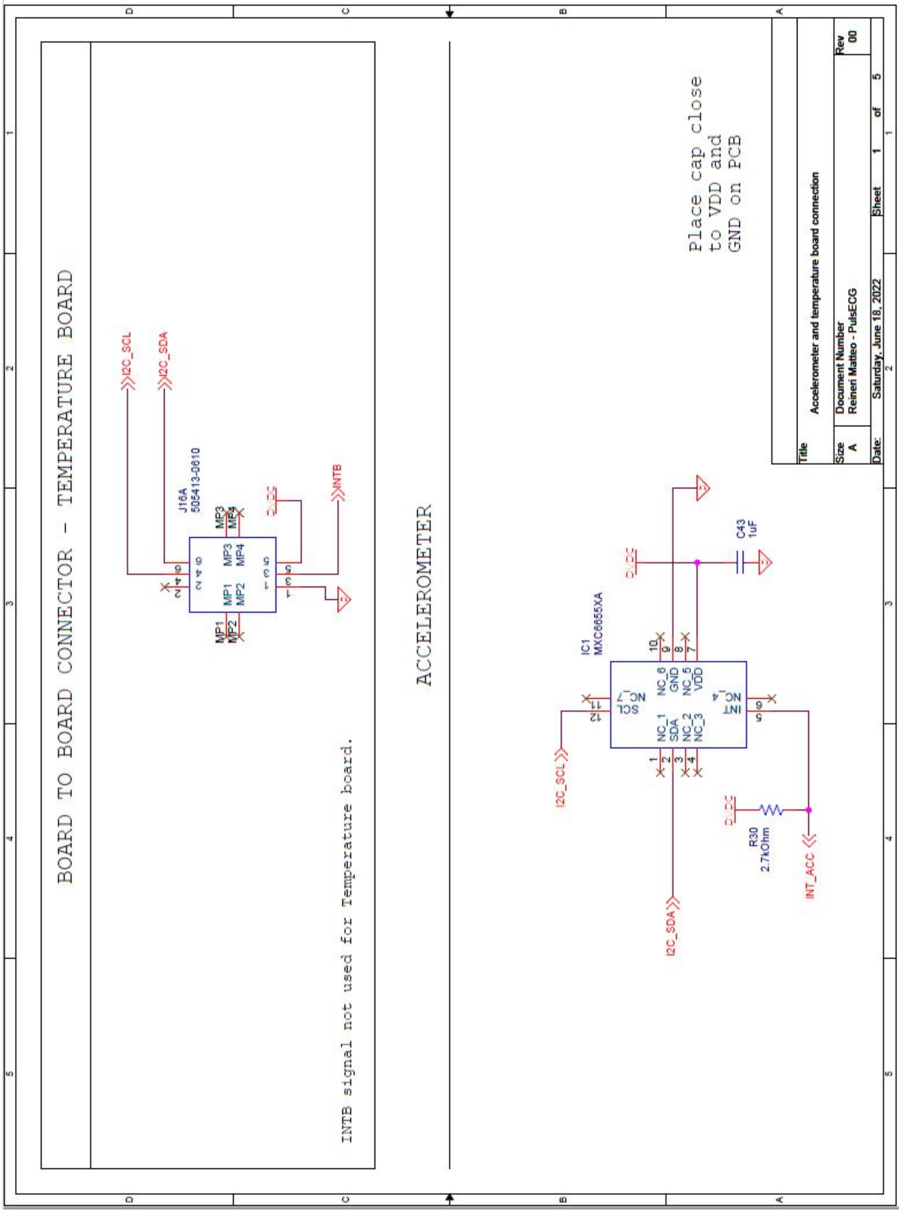


Figure 8.5: ECG board: accelerometer and temperature connection schematic

8.2 PPG board schematics

- PPG: sheet containing the PPG sensor and its passive components needed.
- FLASH MEMORY AND SPI: the sheet dedicated to the flash memory and the SPI-I2C bridge for its communication with the rest of the circuit.

8.2.1 PPG board: PPG sensor section

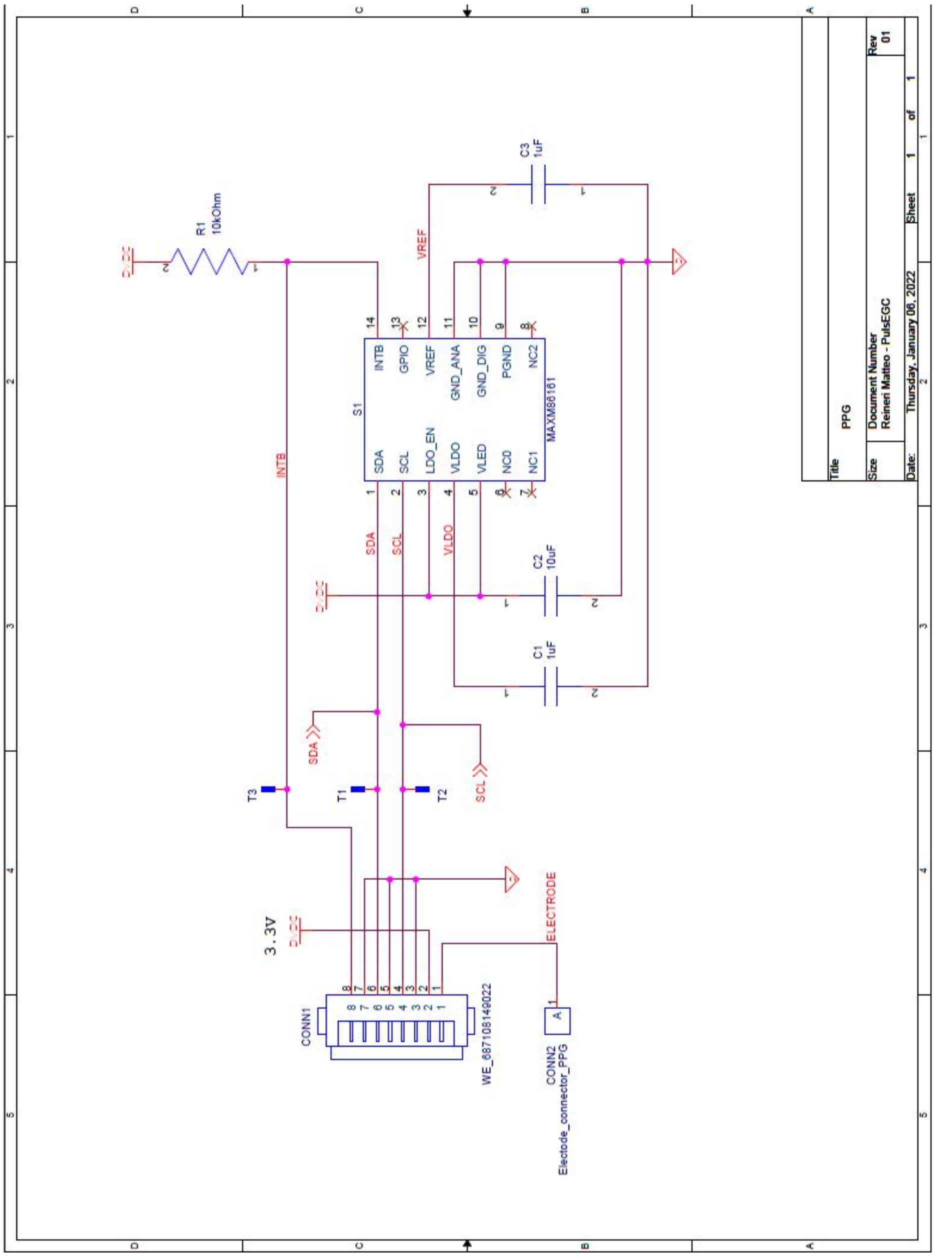


Figure 8.6: PPG board: PPG sensor schematic

8.2.2 PPG board: flash memory section

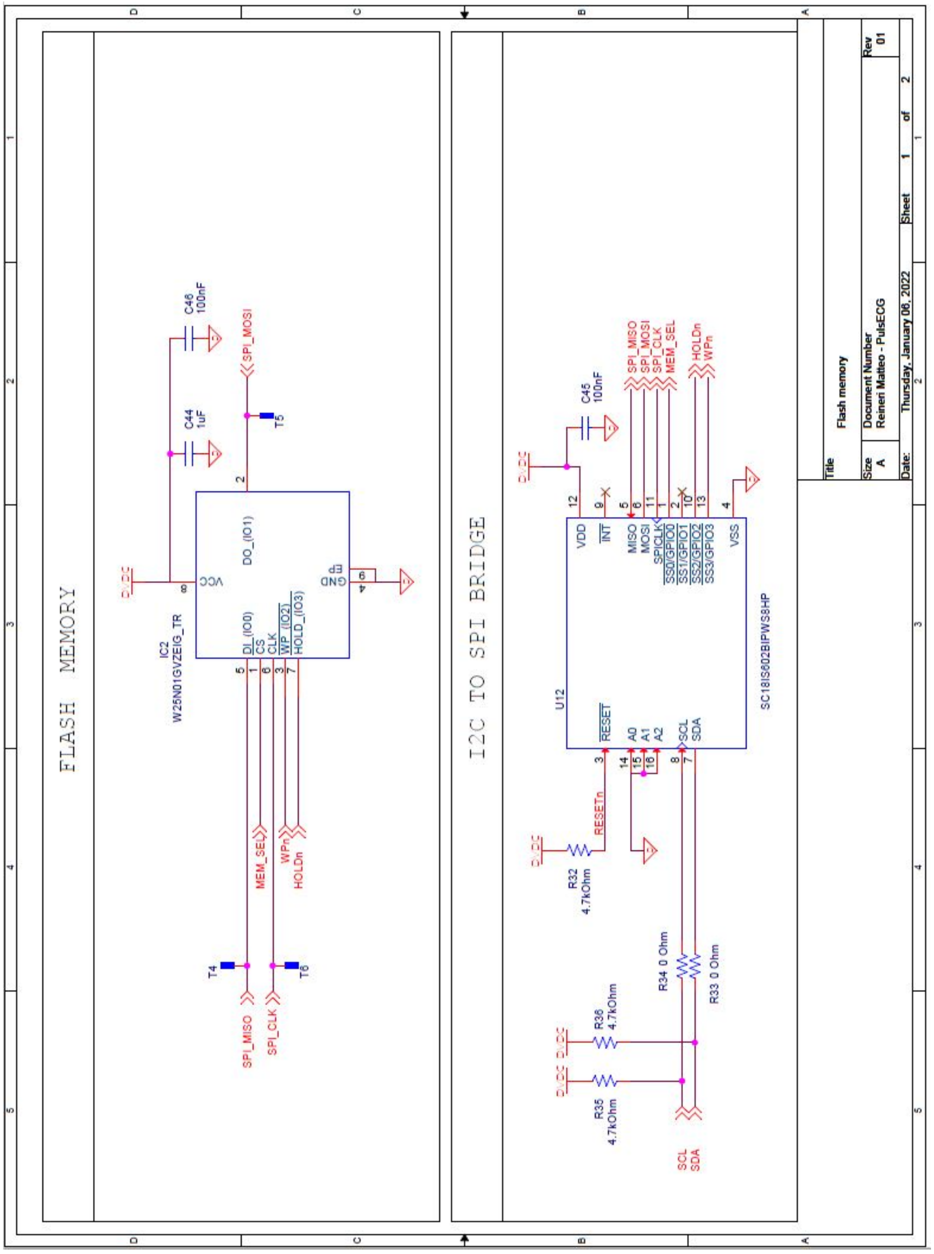


Figure 8.7: PPG board: memory schematic

8.3 Temperature board schematics

- "Temperature", with the sensor and the board to board connector.

8.3.1 Temperature board: temperature sensor and connector

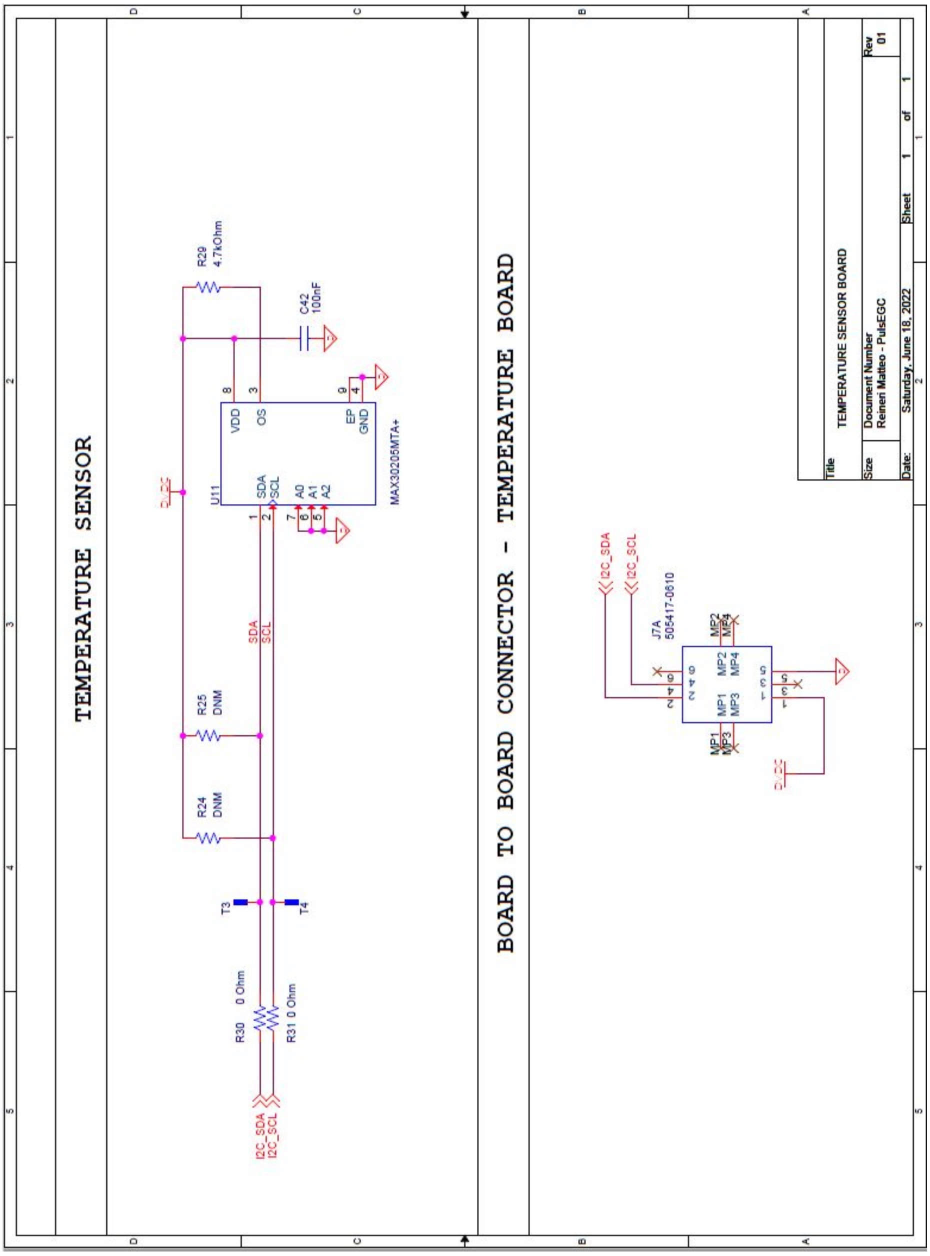


Figure 8.8: Accelerometer and temperature sensor schematic

8.4 ECG watch board schematics

ECGwatch project has the same schematics of ECG board of PulsECG, without the sheet ”Accelerometer and temperature”. So, 4 sheets for it: power management, microcontroller, microcontroller DIOs and analog front-end.

8.4.1 WatchECG: analog front-end section

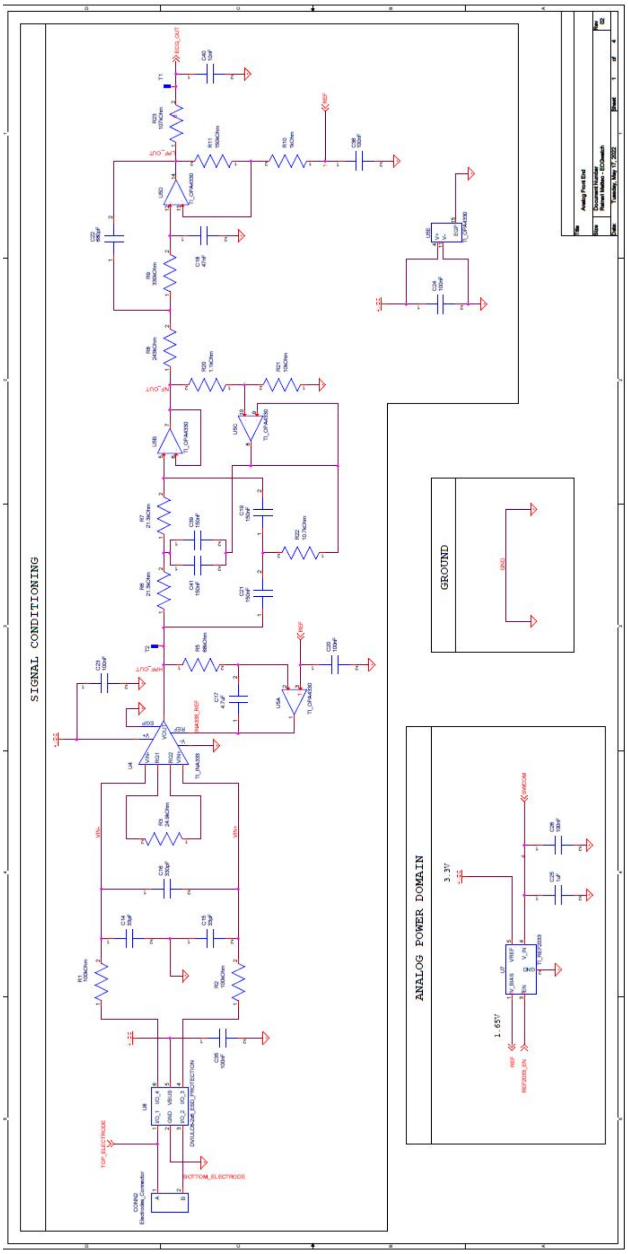


Figure 8.9: Power management schematic

8.4.2 WatchECG: microcontroller section

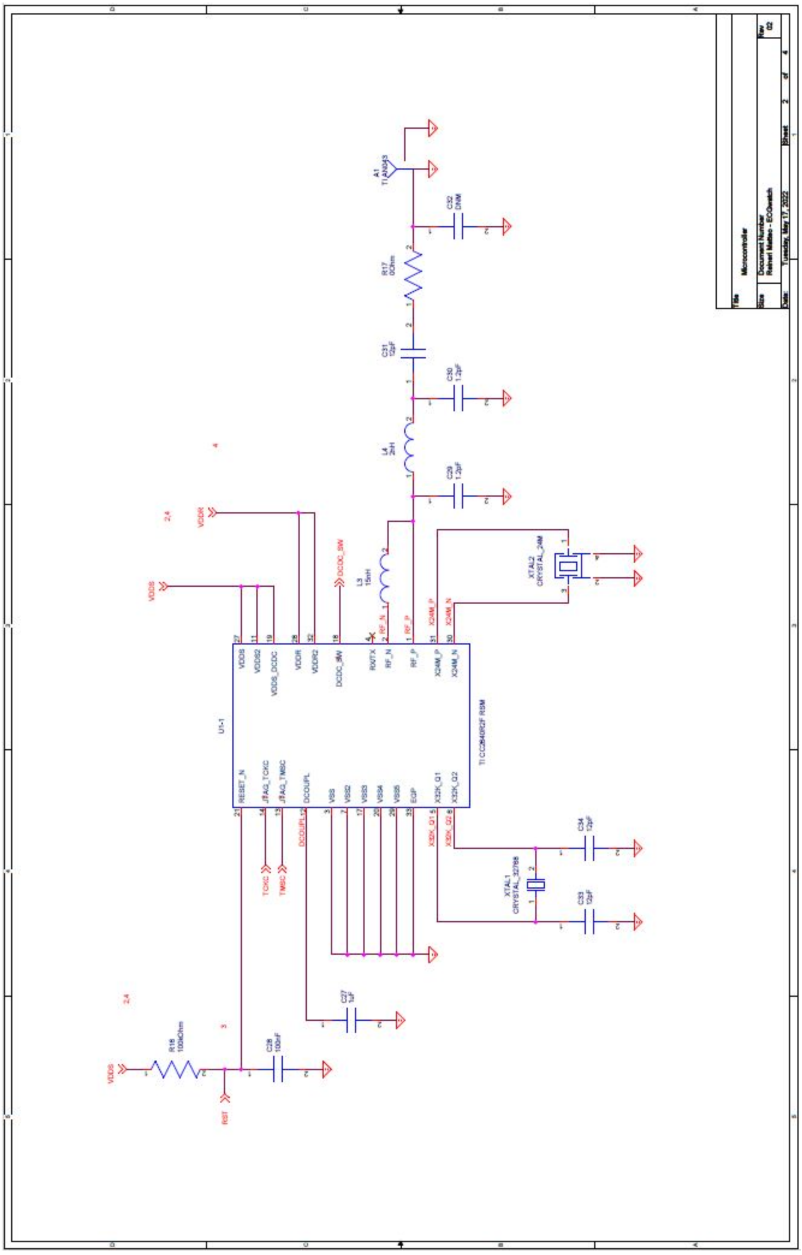


Figure 8.10: Power management schematic

8.4.3 WatchECG: microcontroller DIOs section

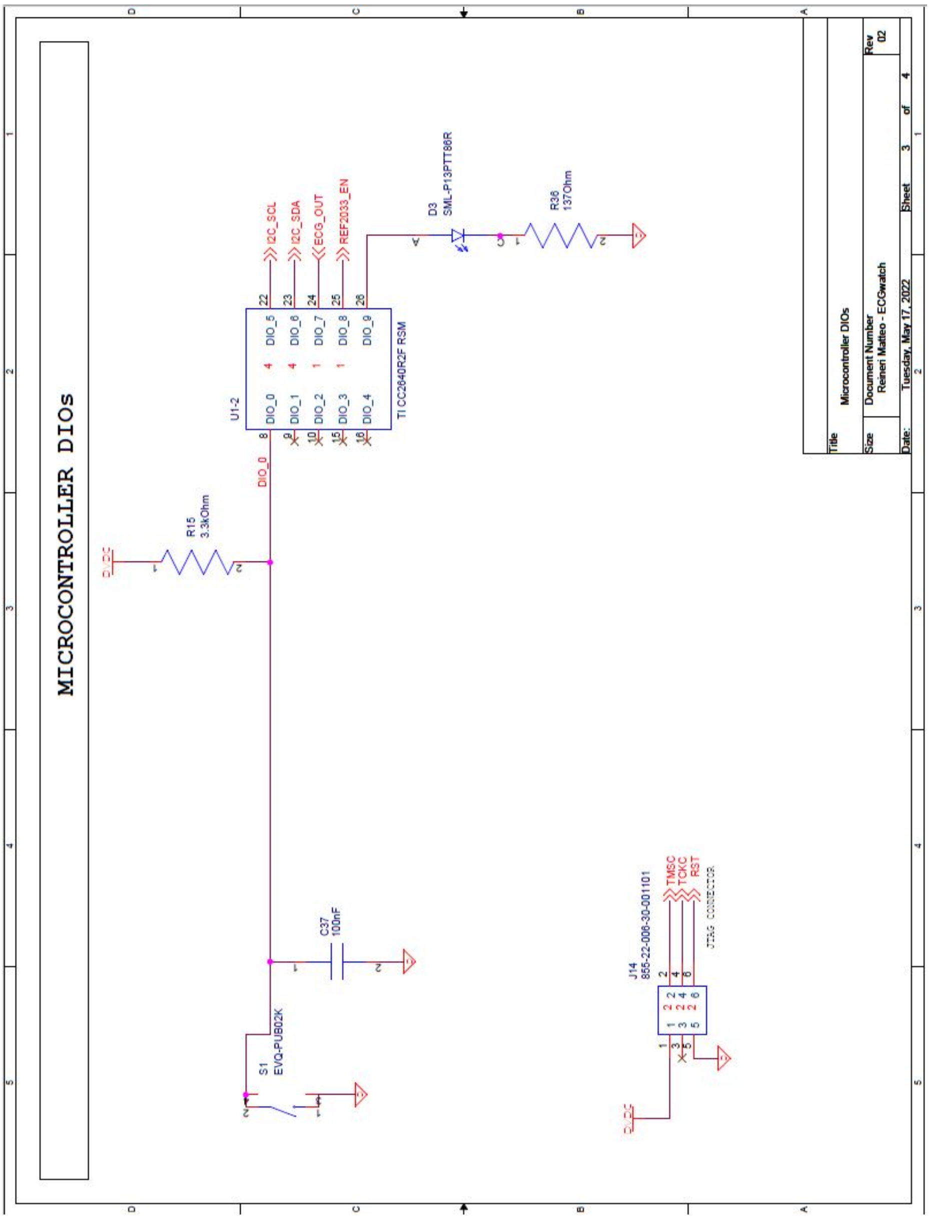


Figure 8.11: Power management schematic

8.4.4 WatchECG: power management section

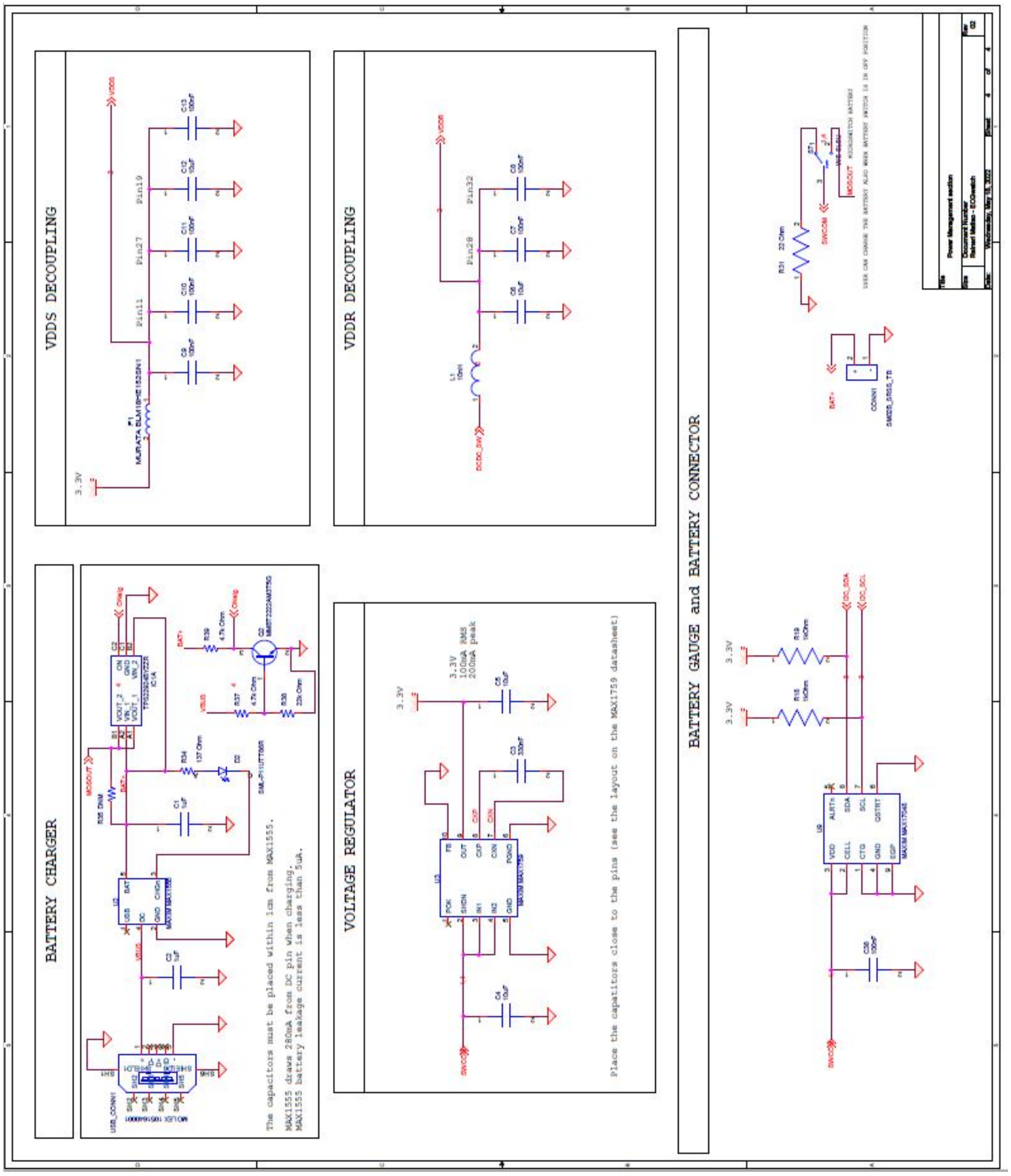


Figure 8.12: Power management schematic

CHAPTER 9

Allegro boards

9.1 PulsECG

9.1.1 ECG board

The ECG board keeps the same structure of the previous version, with:

- The battery and micro-USB connection in the top left of the drawing
- The BLE antenna on the left
- The ecg analog front-end on the right side
- The microcontroller in the middle of the board

New components location are focused in the second image.

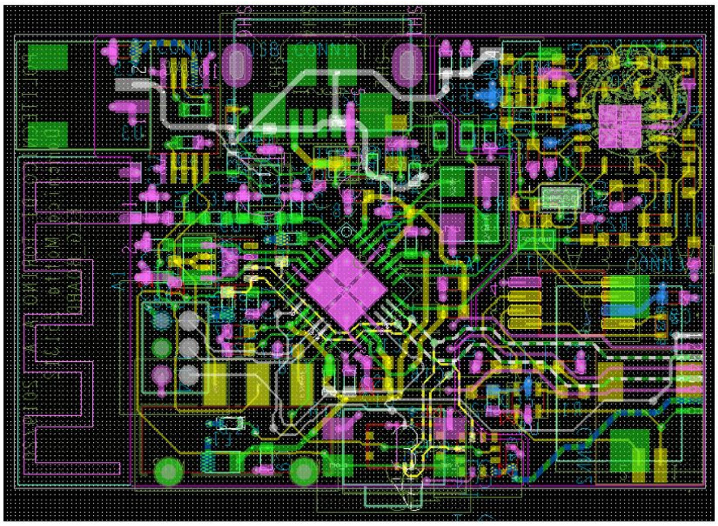


Figure 9.1: PulsECG: ECG board

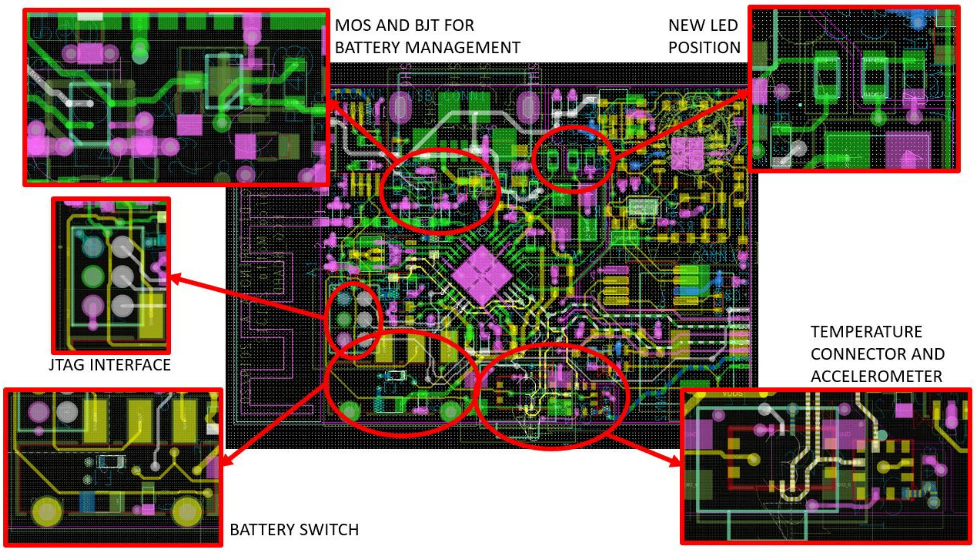


Figure 9.2: ECG board focus

9.2 PPG board

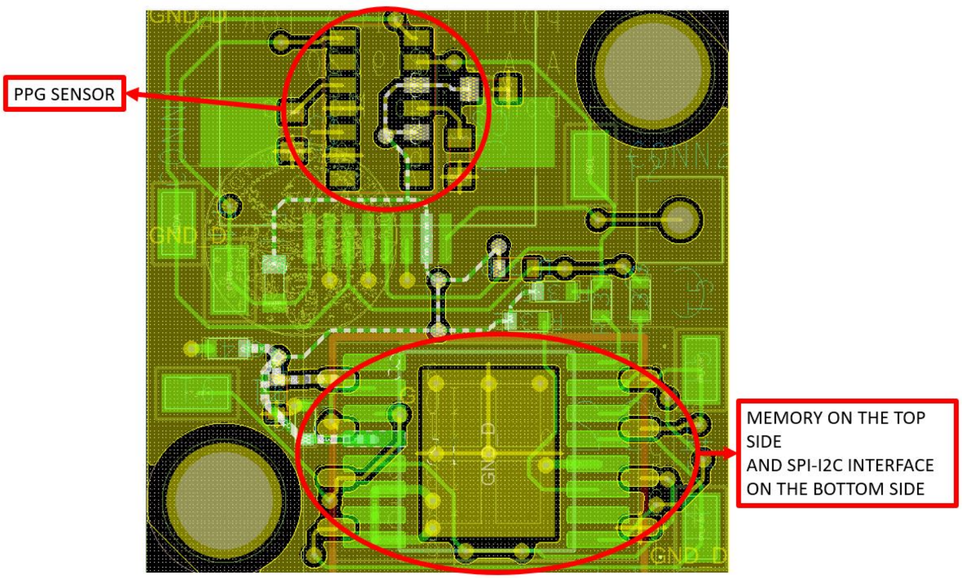


Figure 9.3: PulsECG: PPG board

9.3 Temperature board

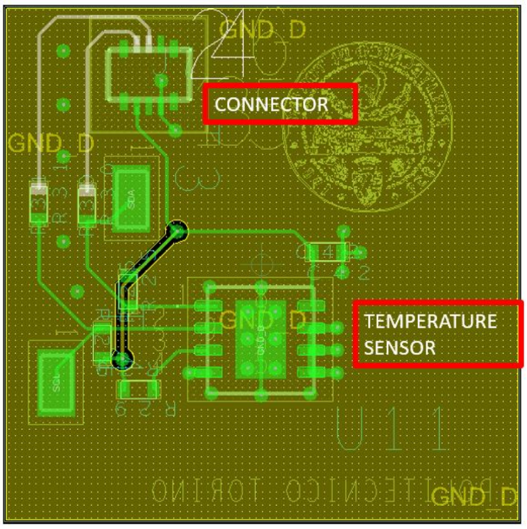


Figure 9.4: PulsECG: temperature board

9.4 JTAG board

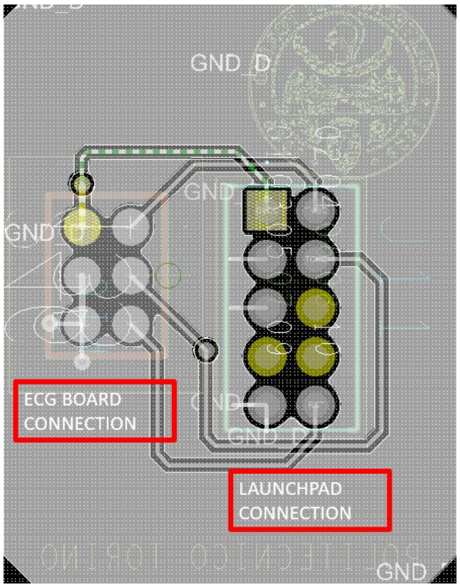


Figure 9.5: PulsECG: JTAG board

9.5 ECGwatch board

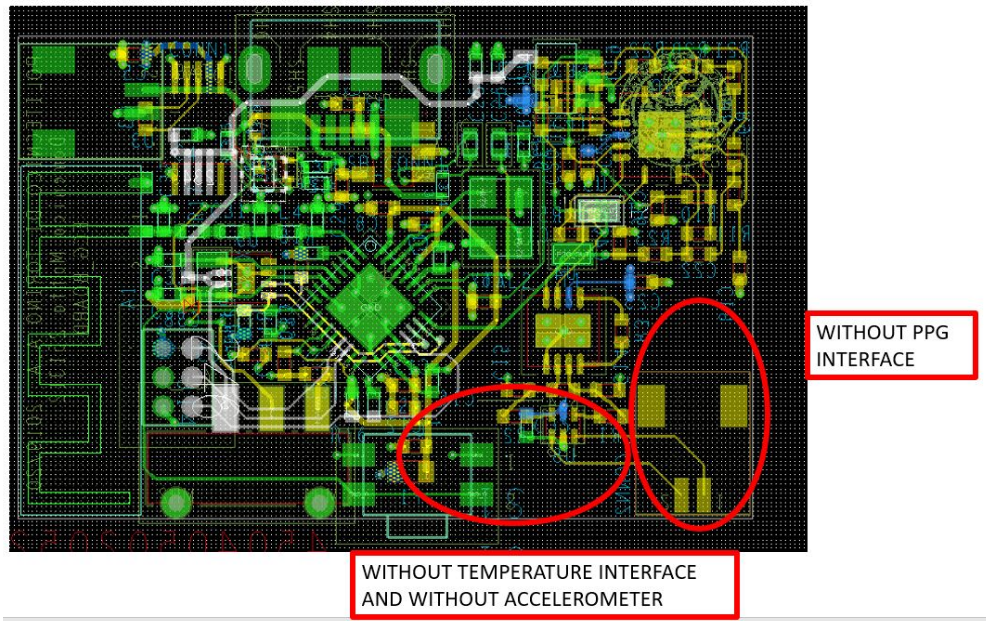


Figure 9.6: ECG watch board

CHAPTER 10

Final prototype view

At the end of the assembly , PulsECG appear like in the following images:

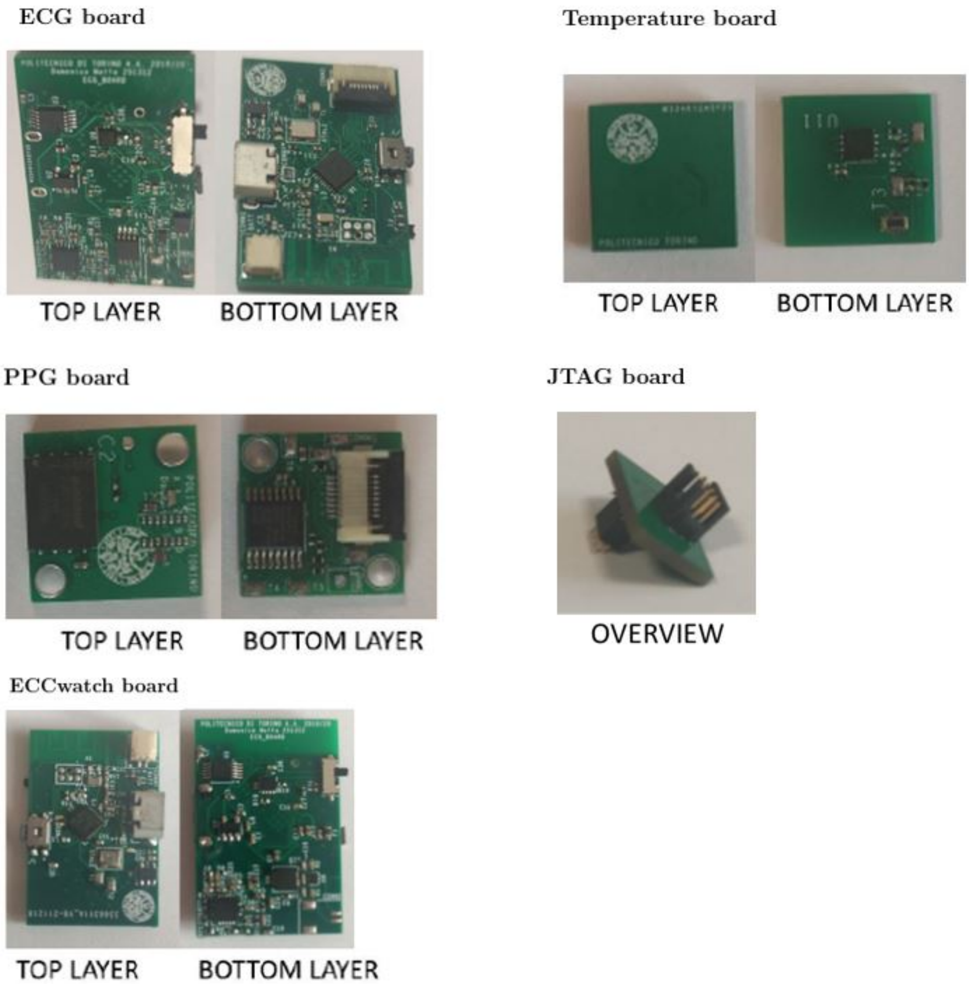


Figure 10.1: Boards final view

About the temperature board, the TOP layer is total empty because it will be in contact directly to the finger or an electrode interface. The PPG board in the image has not the Maxime 17048 sensor, because the not availability of the component in the market. Since memory integration has been left for other projects, for the validation phase a old simple PPG board is used. In the next image, the assembly of the three boards which make up the new PulsECG:

Figure 10.2: PulsECG final view

CHAPTER 11

Testing & validation

In order to be able to verify that the board update and component soldering activities have been properly performed, a simple ECG and PPG acquisition through the application was performed. Already implemented in the previous PulsECG version, it was important know that the new implementations have not affected existing functionality. About the new component, some dedicated codes were integrated inside the already existing firmware. Each code, performed individually, was written to test only one of the new features included in this latest version of PulsECG. Code development and full integration with existing PulsECG firmware and application is left for future projects. The new codes were added at the beginning, before the ECG and PPG acquisitions already developed in the previous project started. It was thus possible to visualize in debug mode the behaviors of the new sensors.

11.1 ECG and PPG acquistion

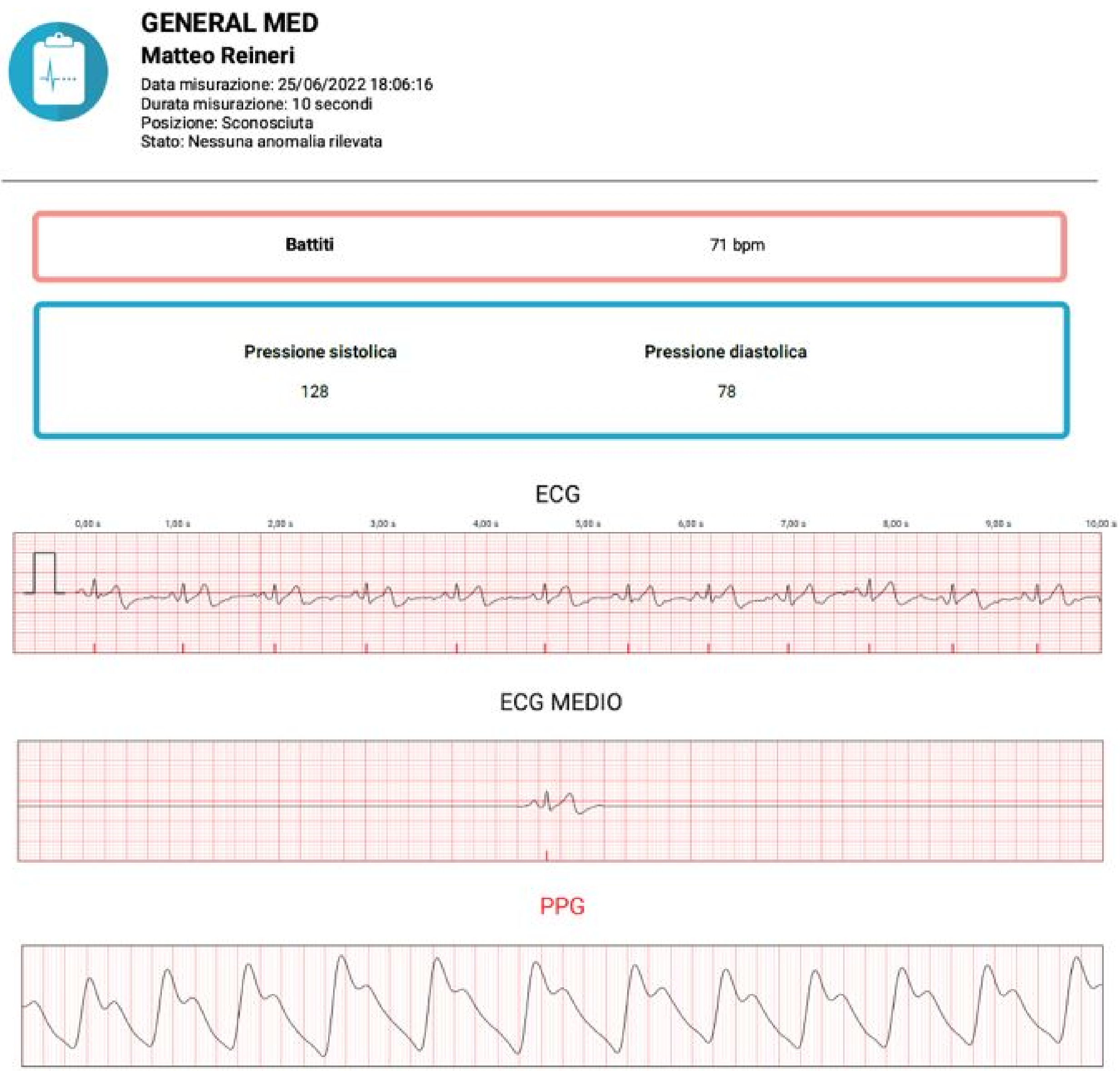


Figure 11.1: ECG and PPG acquistion

The above acquisition demonstrates that ECG and PPG measurements are performed correctly.

11.2 Accelerometer test

The ideal condition would have been perform the test with the Bluetooth communication and the smartphone application able to send and read the data of the sensor. Since these features have not yet been implemented, the debug mode of code composer studio was used to test the accelerometer. The debug mode allow the user to run the firmware code inside the board and read the values inside the registers during its execution.

11.2.1 Accelerometer firmware

```
static int16_t z[ECG_BUFFER_SIZE*2];
static int16_t x[ECG_BUFFER_SIZE*2];
static int16_t y[ECG_BUFFER_SIZE*2];
int16_t        z_val, x_val, y_val;

// VERIFICA NAME ID
transaction.writeCount = 1; //Number of byte to send (write)
transaction.readCount = 1; //Number of byte to receive (read)
writeBuffer1[0] = 0x0F; //register of ID accelerometer
transaction.slaveAddress = ACC_ADDRESS; //0x15
if (!I2C_transfer(i2cHandle, &transaction)) {
  while(1);
}
if (readData2[0]!=0x05){ //correct ID=0x05
  while(1);
}

//OPERATING MODE SETUP
transaction.writeCount = 2; //Number of byte to send (write)
transaction.readCount  = 0; //Number of byte to receive (read)
writeBuffer1[0] = 0x0D; //MODE REGISTER
writeBuffer1[1] = 0x00; // 00=2g 1024res, 20=4g, 40=8g
transaction.slaveAddress = ACC_ADDRESS; //0x15
if (!I2C_transfer(i2cHandle, &transaction)) {
  while(1);
}

//ACQUISITION
for(int time=0; time<ECG_BUFFER_SIZE*2; time++){//200 SAMPLES

  //ORIENTATION STATUS
  transaction.writeCount = 1; //Number of byte to send (write)
  transaction.readCount  = 1; //Number of byte to receive (read)
  writeBuffer1[0] = 0x02; //orientation register
  transaction.slaveAddress = ACC_ADDRESS; //0x15
  if (!I2C_transfer(i2cHandle, &transaction)) {
```

```
      while(1);
    }

    transaction.writeCount = 2; //Number of byte to send (write)
    transaction.readCount  = 2; //Number of byte to receive (read)
    writeBuffer1[0] = 0x03; //X upper register (8bit)
    writeBuffer1[1] = 0x04; //X lower register (4 bit + 0000)
    if (!I2C_transfer(i2cHandle, &transaction)) {
      while(1);
    }
    x_val= ((uint16_t)readData2[0] << 8) | readData2[1]; //16bit value
   with 4LSB useless
    x[time]=(x_val>>4); //12 bit value


    writeBuffer1[0] = 0x05; //Y upper register (8bit)
    writeBuffer1[1] = 0x06; //Y lower register (4 bit + 0000)
    if (!I2C_transfer(i2cHandle, &transaction)) {
      while(1);
    }
    y_val= ((uint16_t)readData2[0] << 8) | readData2[1]; //16bit value
   with 4LSB useless
    y[time]=(y_val>>4); //12 bit value


    writeBuffer1[0] = 0x07; //Z upper register (8bit)
    writeBuffer1[1] = 0x08; //Z lower register (4 bit + 0000)
    if (!I2C_transfer(i2cHandle, &transaction)) {
      while(1);
    }
    z_val= ((uint16_t)readData2[0] << 8) | readData2[1]; //16bit value
   with 4LSB useless
    z[time]=(z_val>>4); //12 bit value

    Task_sleep(2500); //duration for cycle: 10s.
  }

```

Accelerations values are in vectors x[ ], y[ ] and z[ ].
x_val, y_val and z_val are only temporary variables used for data elaboration.

11.2.2 Orientation test

One of the most common information that accelerometers can give is its position in space. To do so, it uses the gravity: depending on the axis on which it feels the exertion of this force, it can figure out which way the clock is positioned relative to the vertical. The following table lists all the possible positions it can take:

- In "BOARD" column there is the picture of the board under test, at the position where the measurement was taken
- In "AXIS" column the is the indication of the axis position referred to the related board position in the picture.
- In "HEX BYTE" column there is the value of the accelerometer position register, obtained during the measurement, in hexadecimal value.
- In "POS" columns the register value is unpacked obtaining the bit useful to have the space information for each axis.
- In "POSITION" there is the POS values explanation.

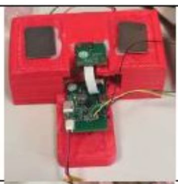
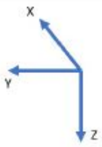
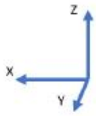
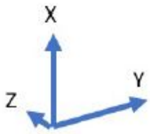
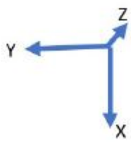
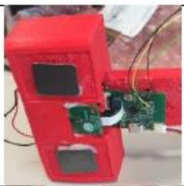
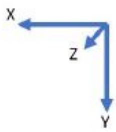
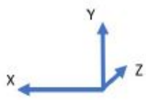
BOARD	AXES	HEX BYTE	POS[3]	POS[2]	POS[1]	POS[0]	POSITION
		0x1F 0x1D 0x1C 0x1E	1 1 1 1	1 1 1 1	1 0 0 1	1 1 0 0	-Z con inclinazione tendente a -Y -Z con inclinazione tendente a +Y -Z con inclinazione tendente a +X -Z con inclinazione tendente a +X
		0x18 0x19 0x1B 0x1A	1 1 1 1	0 0 0 0	0 0 1 1	0 1 1 0	+Z con inclinazione tendente a +X +Z con inclinazione tendente a +Y +Z con inclinazione tendente a -Y +Z con inclinazione tendente a -X
		0x14 0x10	0 0	1 0	0 0	0 0	+X con inclinazione tendente a -Z +X con inclinazione tendente a +Z
		0x16 0x12	0 0	1 0	1 1	0 0	-X con inclinazione tendente a -Z -X con inclinazione tendente a +Z
		0x17 0x13	0 0	1 0	1 1	1 1	-Y con inclinazione tendente a -Z -Y con inclinazione tendente a +Z
		0x15 0X11	0 0	1 0	0 0	1 1	+Y con inclinazione tendente a -Z +Y con inclinazione tendente a +Z

Figure 11.2: Accelerometer orientations

11.2.3 Acceleration test

To validate the accelerometer behavior in dynamic conditions, a free fall test was registered.
The board was dropped while running the program in debug mode. Then, the log data were copied to text files and processed through a matlab script. The test has a duration of 10 seconds, with 200 values measured for each axis. Tha samples are in the third column of the text file, as in example:

```
AXIS X SAMPLES FILE EXAMPLE
---------------------------------------

[0]     short   980     0x20001B30
[1]     short   978     0x20001B32
[2]     short   970     0x20001B34
[3]     short   962     0x20001B36
[4]     short   964     0x20001B38
[5]     short   958     0x20001B3A
[6]     short   962     0x20001B3C
[7]     short   976     0x20001B3E
[8]     short   970     0x20001B40
[9]     short   962     0x20001B42
...
[193]   short   221     0x20001CB2
[194]   short   220     0x20001CB4
[195]   short   219     0x20001CB6
[196]   short   220     0x20001CB8
[197]   short   223     0x20001CBA
[198]   short   229     0x20001CBC
[199]   short   221     0x20001CBE
```

The table is worked and unpacked through the following matlab script, that give us a plot with the acceleration registered along the three axis.

```
%SCRIPT FOR ACCELERATIONS ELABORATION

%FROM TXT TO TABLE FOR Z FILE
filenameZ = fopen("Zsamples.txt");
optsZ = detectImportOptions('Zsamples.txt');
Zs = readcell('Zsamples.txt',optsZ)

%FROM TXT TO TABLE X FILE
filenameX = fopen("Xsamples.txt");
optsX = detectImportOptions('Xsamples.txt');
Xs = readcell('Xsamples.txt',optsX)
```

```
%FROM TXT TO TABLE FOR Y FILE
filenameY = fopen("Ysamples.txt");
optsY = detectImportOptions('Ysamples.txt');
Ys = readcell('Ysamples.txt',optsY)

%VALUES OF ACCELERATION IN COLUMN 3
%COLUMN 3 EXTRACTION FROM THE TABLE
for i=1:199
Xp(i)=Xs(i,3); %EXTRACTION OF THE CELLS
X(i)=str2num(string(Xp(i))); %FROM CELL TO NUMBER
X(i)=X(i)/(1024); %FROM NUMBER TO GRAVITY VALUE IN g

Yp(i)=Ys(i,3); %EXTRACTION OF THE CELLS
Y(i)=str2num(string(Yp(i))); %FROM CELL TO NUMBER
Y(i)=Y(i)/(1024);

Zp(i)=Zs(i,3); %EXTRACTION OF THE CELLS
Z(i)=str2num(string(Zp(i))); %FROM CELL TO NUMBER
Z(i)=Z(i)/1024; %FROM NUMBER TO GRAVITY VALUE IN g
Z(i)=Z(i)+0.25; %FOR Z AN OFFSET OF +0.25g IS NEEDED
end

t=linspace(1, 199, 199);
plot(t,Z,t,X,t,Y)
```

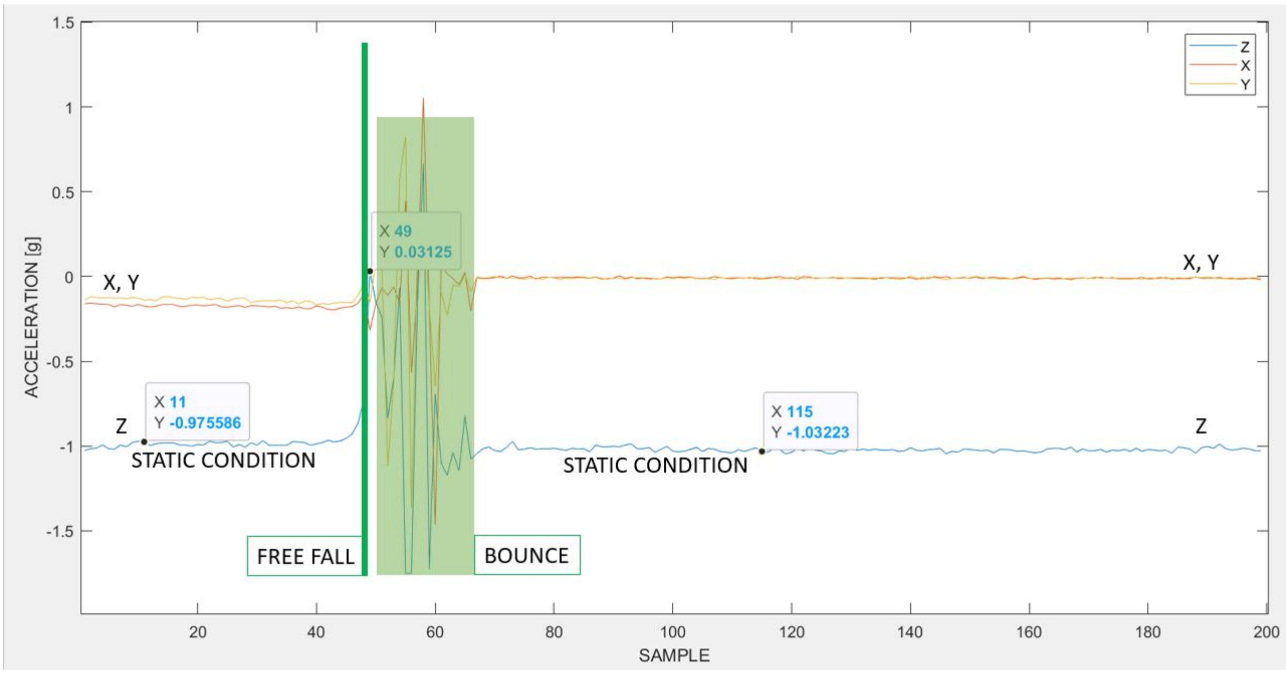


Figure 11.3: Accelerometer plot

Even when stationary, the accelerometer senses the force of gravity. This implies that under static conditions on the vertical axis it will never read acceleration=0, but +g or -g depending the axis orientation. During free fall, the accelerometer will feel the force of gravity bringing the value close to 0.
It can be seen from the graph that the fall occurred along the Z axis. Since it is impossible to keep the device perfectly straight during the fall, the impact with the ground does not occur with the Z axis perfectly vertical. From this, it follows that the board lands in a disjointed manner and the accelerations/decelerations due to the bounce phase are seen in all axes, before returning to the static condition of the device stationary on the desk.

11.3 Temperature sensor test

The temperature sensor test was performed with the same method used for the accelerometer test. Using Code Composer Studio, a data vector ”t” containing the temperature sensor measurements was created (see image below).

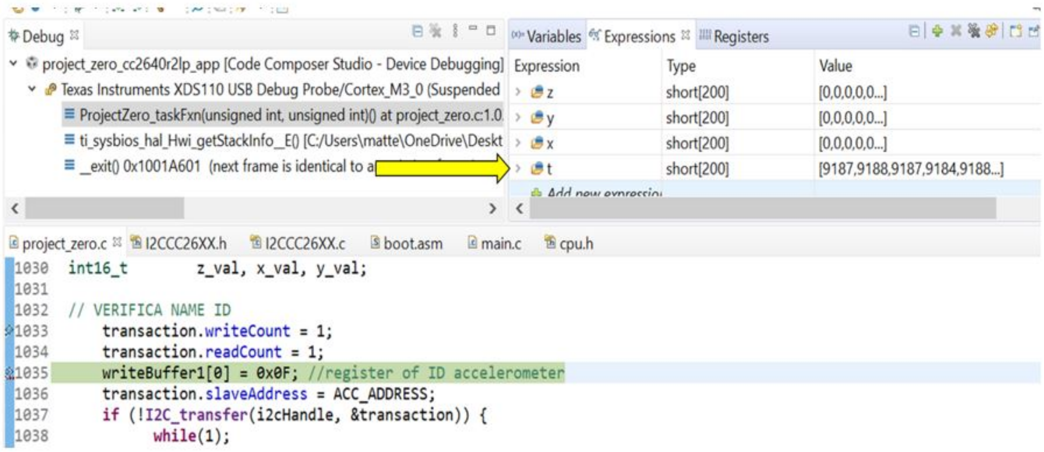


Figure 11.4: CCS debug mode window

Values in the vector are displayed in decimal numbers without units. To obtain the corrisponding temperature, it is necessary multiply thedecimal value by the resolution of 0.00390625 LSB/°C. This is done by the matlab script that is responsible for extracting values and creating graph.

```
 %SCRIPT FOR TEMPERATURES ELABORATION

%FROM TXT TO TABLE FOR T FILE
filenameT = fopen("Tsamples.txt");
optsT = detectImportOptions('Tsamples.txt');
Ts = readcell('Tsamples.txt',optsT);

%VALUES OF TEMPERATURE IN COLUMN 3
%COLUMN 3 EXTRACTION FROM THE TABLE
for i=1:299
Tp(i)=Ts(i,3); %EXTRACTION OF THE CELLS
T(i)=str2num(string(Tp(i))); %FROM CELL TO NUMBER
T(i)=T(i)*0.00390625; %FROM NUMBER TO TEMP


end

t=linspace(1, 299, 299);
plot(t,T)
```

11.4 Termometer firmware test

```
static uint16_t   sample;
static int16_t    t[300];

transaction.writeCount = 1; //Number of byte to send (write)
transaction.readCount = 1; //Number of byte to receive (read)
writeBuffer1[0] = 0x01; //Configuration register
transaction.slaveAddress = MAX30205_ADDRESS;//MAX30205_ADDRESS=0x48

if (!I2C_transfer(i2cHandle, &transaction)) {
  /* Could not resolve a sensor, error */
  while(1);
}

for (sample = 0; sample < 300; sample++) {
  transaction.writeCount = 1; //Number of byte to send (write)
  transaction.readCount = 2; //Number of byte to receive (read)
  writeBuffer1[0] = MAX30205_TMPREG; // MAX30205_TMPREG=0x00
  if (I2C_transfer(i2cHandle, &transaction)) {
    //max3025 gives value in 2 bytes
    t[sample] = (readData2[0] << 8) | (readData2[1]);
  }
  // Sleep for 1 second
  Task_sleep(50000); //100SEC, 2SAMPLES/SEC
}

```

In vector t[] there are all the temperature measurement done during the for cycle.

11.4.1 Ambient temperature test

The first test carried out is the verification of the correct measurement of ambient temperature. The values measured by the sensor were compared with the temperature read by the max30205 evaluation board in the picture:

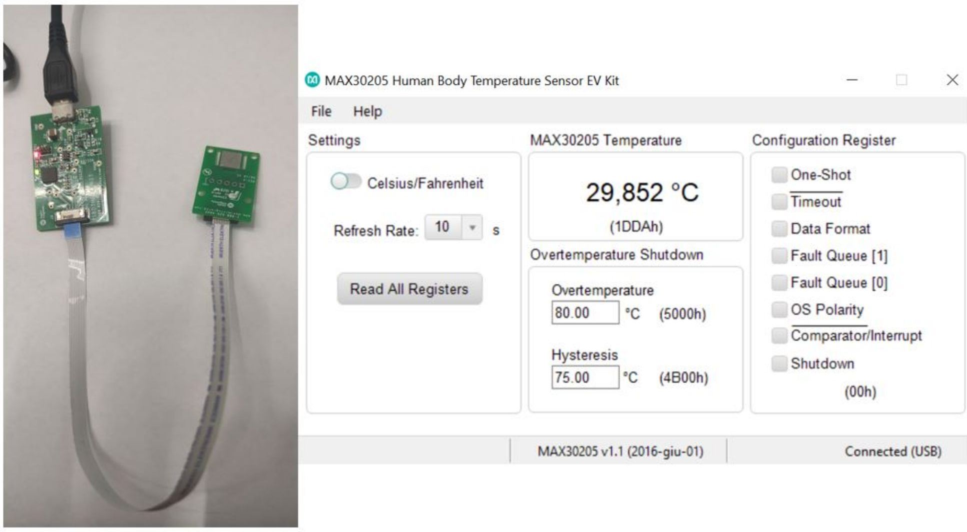


Figure 11.5: Ambient temperature with evaluation board

The temperatures measured with PulsECG are in line with the values displayed with the evaluation board.

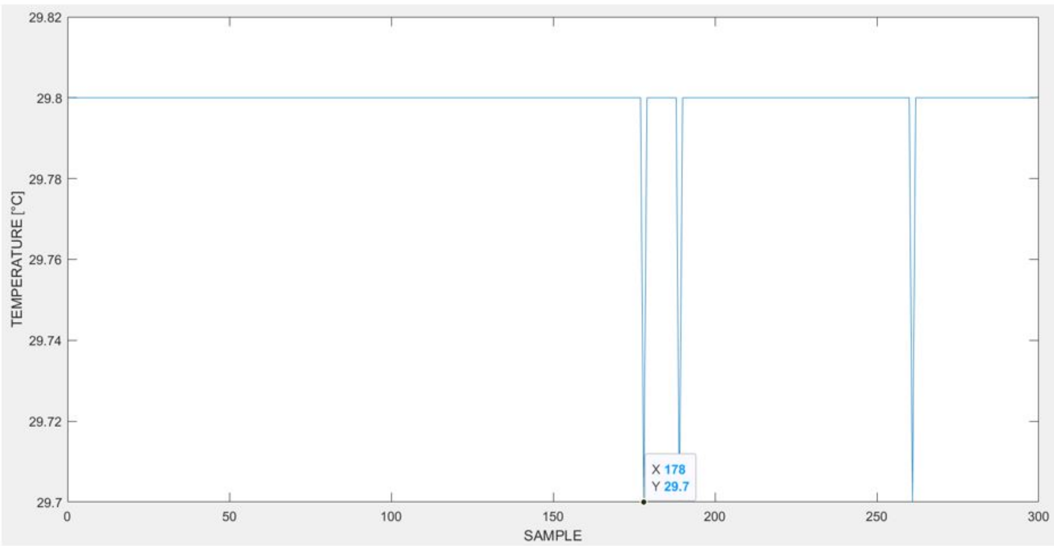


Figure 11.6: Ambient temperature with PulsECG

11.4.2 Finger temperature test

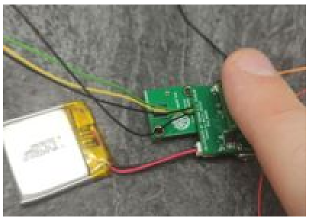


Figure 11.7: Finger temperature measurement mode

The measurement is taken by holding the finger over the temperature board for 150 seconds (2 1/2 minutes). Also in this case, temperatures of PulsECG and the evaluation board are very similar.

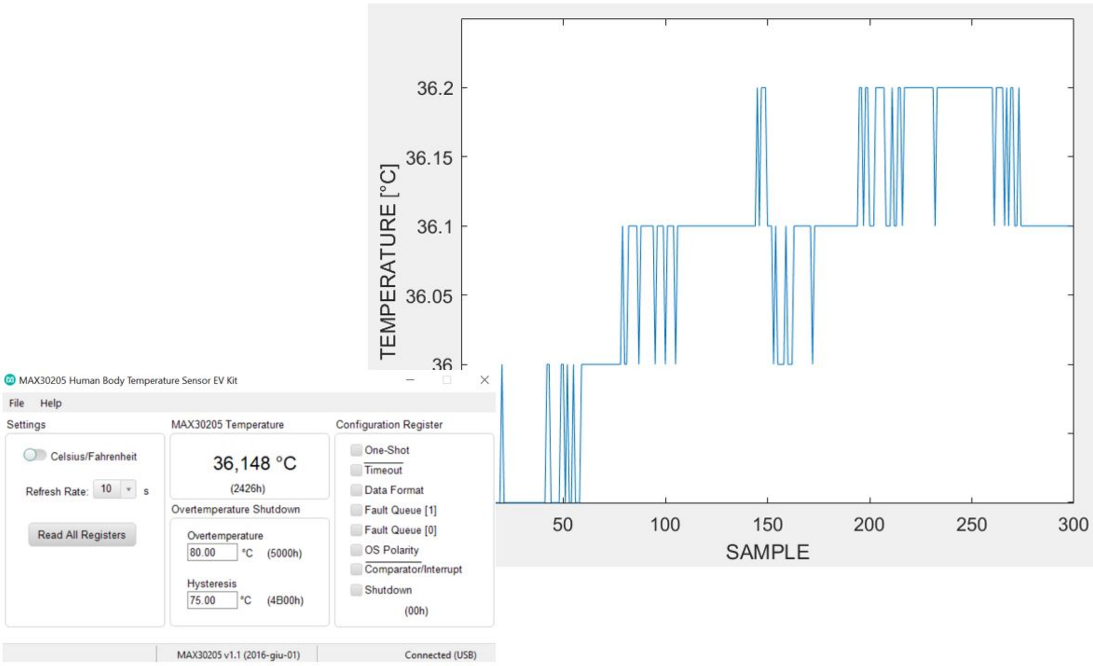


Figure 11.8: Finger temperature measurement done at 31°C

It is very difficult in testing phase determine the accuracy of the measured body temperature (in this case of the finger of the hand), as this is strongly influenced by the characteristic of individual person and the outside temperature. What can be said is that under the conditions in which the measurement was performed, temperature values around 36°C are still realistic. The condition in which the human body has a generally very homogeneous temperature is precisely that in which the ambient temperature is high, while at low temperatures the differences can be large, depending on where the measurement is located. An example is the second acquisition shown below, taken not at 31°C but in a 27°C air-conditioned environment on the same subject. In this case, the finger temperature is 33.5°C, which shows how a difference of 4°C in the environment can alter the skin temperature, which the body self-regulates to stabilize its internal temperature as much as possible.

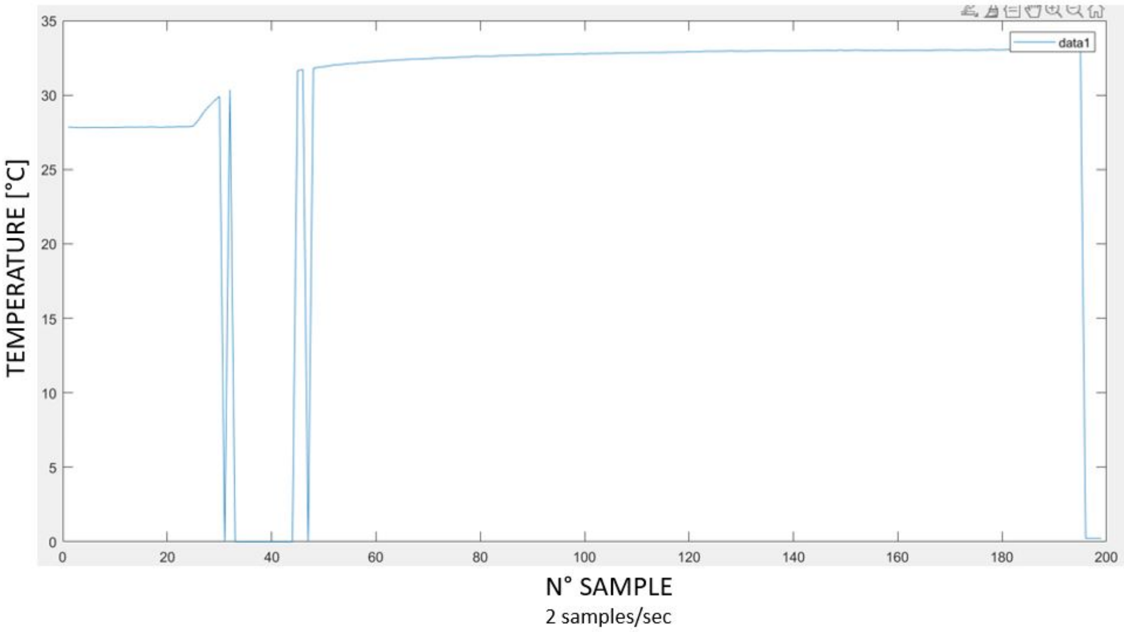


Figure 11.9: Finger temperature measurement done at 27°C

CHAPTER 12

Conclusions

Dimensionally, the goal of adding the desired functionality without changing the size of the watch was achieved. The temperature sensor adds more medical functionality than the previous version, while the accelerometer allows for highly accurate interpretation of how PulsECG is being used. On the hardware side, it was seen in testing that some optimizations could be made: the main one is to change the connection between the temperature board and the ECG board. It would be necessary to separate the two boards further so that the temperature sensor would be affected as little as possible by the rest of the clock. However, having upgraded the smartwatch on the hardware side, the greatest progress that could be made in my opinion is directed at the software side. Without having to add additional components to the board, firmware integration of the accelerometer today could enable PulsECG to:

- Maximize battery life when the watch is not in use. You could set the watch to standby mode when the accelerometer does not detect acceleration and movement for a specified period of time.
- Warn the user of incorrect ECG measurements due to measurement conditions that are not properly at rest. In this case, a pop-up may pop up on the application when abrupt movements are detected during resting acquisitions.

Deeper developments of the watch also on the hardware side could make the accelerometer:

- Automatically turn on a display, a feature already present on the most common smartwatches on the market.
- Alert the user or initiate automatic alarm calls whenever the accelerometer detects falls in the watch, a possible cause of user discomfort.

As for the temperature sensor, the most important and difficult task will be to make the information as accurate as possible. Some of the factors that can help to best interpret the data are:

- Knowledge of ambient temperature, which greatly affects the homogeneity of heat on the human body
- Generic user information, such as gender and age, may give indications of possible individuals with lower-than-average skin temperatures.
- Know the number of heartbeats you have during the measurement. Liebermeister's rule [17] shows how a 1°C increase in body temperature corresponds to an 8/10 beats per minute increase in heart rate.

By extending the view beyond PulsECG and smartwatches, medical wearable devices may increasingly be part of everyone's lives. The trend is to embed devices in accessories or clothing that are widely popular and already routinely worn by everyone (e.g., headphones, gloves, socks) [42]. This is because it is more convenient and becomes more easily popular to use these technologies if they are invisible. The user does not have to worry about carrying an extra item with him or her, and most importantly, does not have accessories with him or her that could manifest particular weaknesses or diseases externally. One of the next features that could reach a large number of the world's population could be wearable devices that analyze the user's walk to predict Alzheimer's disease, a disease strongly linked to walking [43]. Other wearable devices on the launch pad are sweat sensors to calculate the body's dehydration, or devices that monitor the presence of cancer cells in the blood.

CHAPTER 13

Bibliography

[1] ”Wearable medical devices market - growth, trends, covid-19 impact, and forecasts (2021-2026).” https://www.mordorintelligence.com/industry-reports/global-wearable-medical-device-market-industry

[2] ”Apple and Stanford Medicine fire up Heart Study to spot irregular beat, atrial fibrillation.” https://appleinsider.com/articles/17/11/30/apple-and-stanford-medicine-fire-up-heart-study-to-spot-irregular-beat-atrial-fibrillation

[3] ”Wearable Medical Device Market Size, Share & Trends Analysis Report” By Type (Diagnostic, Therapeutic), By Site (Handheld, Headband, Strap, Shoe Sensors), By Application, By Region, And Segment Forecasts, 2022 - 2030

[4] ”Wearable, quale spazio in farmacia per il mercato dell’e-health.” www.pharmacyscanner.it/wearable-mercato-delle-health-la-farmacia-rischia-farsi-sfilare

[5] ”Interpretazione dell’elettrocardiogramma nell’adulto.” https://www.nurse24.it/studenti/indagini-diagnostiche/elettrocardiogramma-interpretazione-infermiere.html

[6] ”Che cosa è saturazione dell’ossigeno?”. https://www.news-medical.net/health/What-is-Oxygen-Saturation-(Italian).aspx

[7] My Personal trainer, Temperatura corporea, 2020. https://www.my-personaltrainer.it/salute/tempera corporea.html

[8] Elcoteam, ”Consigli per la misura della temperatura corporea mediante Infrarossi”, 2020. https://www.elcoteam.com/blog/strumentazione

[9] K. von Liebermeister, "Handbuch der Pathologie und Therapie des Fiebers" Lipsia, 1875.

[10] Il Consiglia Salute, "Come misurare la febbre dal polso", https://www.ilconsigliasalute.com

[11] Motta Domenico, Politecnico di Torino, "Design and Development of a Multi-Parameter Wearable Medical Device, ECG and PPG Watch", 2020.

[12] Texas Instruments, "CC2640R2F SimpleLink™ Bluetooth® 5.1 Low Energy Wireless MCU", SWRS204C – DECEMBER 2016 – REVISED SEPTEMBER 2020

[13] Texas Instruments, "Small Size 2.4 GHz PCB antenna", Application Note AN043, 2008.

[14] Memsic, "Digital Three-Axis Accelerometer MXC6655XA" Formal release date: 2020/1/22.

[15] Mikroelektronika, "Li-Polymer Battery 3.7V 190mAh".

[16] Maxim Integrated, "MAX17048/MAX17049 3uA 1-Cell/2-Cell Fuel Gauge with ModelGauge", 19-6171; Rev 7;

[17] Maxim Integrated, "SOT23 Dual-Input USB/AC Adapter 1-Cell Li+ Battery Chargers", 19-2902; Rev 0;

[18] Maxim Integrated, "Buck/Boost Regulating Charge Pump in uMAX", 19-1600; Rev 0;

[19] STMicroelectronics, DVIULC6-2x6, Ultra low capacitance ESD protection, 2015.

[20] Texas Instruments, "INA333 Micro-Power (50uA), Zerø-Drift, Rail-to-Rail Out Instrumentation Amplifier", 2015.

[21] Texas Instruments, "OPAx330 50-uV VOS, 0.25-uV/°C, 35 uA CMOS Operational Amplifiers Zero-Drift Series", 2016.

[22] Texas Instruments, "REF20xx Low-Drift, Low-Power, Dual-Output, VREF and VREF / 2 Voltage References", 2022

[23] Texas Instruments, "TPS22924x 3.6-V, 2-A, 18.3-mOhm On-Resistance Load Switch", 2015

[24] On Semiconductor, MMBT2222AM3/D, "NPN General Purpose Transistor", 2017.

[25] Micro-USB B Receptacle without Flange, Top Mount, Surface Mount, Lead-Free, 08/31/2021

[26] JST, SH connector, 1.0mm pitch/Disconnectable Crimp style connectors;

[**27**] Wurth Elektronik, ”WR-FPC SMT ZIF Horizontal Hinge Type ”, 2021.

[**28**] Molex, SlimStack Board-to-Board Receptacle, 0.35mm Pitch, SSB RP Series, 0.90 or 1.00mm Mated Height, 2.00mm Mated Width, 6 Circuits, Armor Nail;

[**29**] Panasonic, Small-sized Side-operational SMD, Light Touch Switches/EVQPU, 2012.

[**30**] Wurth Elektronik, ”WS-SLSU SMT Mini Slide Switch, Same side connection”, 2021.

[**31**] Rohm, SML-P11x Series Datasheet, 2020.4 - Rev.012.

[**32**] Rohm, SML-P12x/P13x Series Datasheet, 2020.4 - Rev.013.

[**33**] Seiko Instruments Micro Energy, ”SMD Quartz Crystal Unit”, SC-20S.

[**34** Seiko Epson Corporation, ”MHz Range Crystal Unit”, TSX-3225.

[**35**] Maxim Integrated, ”Single-Supply Integrated Optical Module for HR and SpO2 Measurement”, Rev 0;

[**36**] Spiflah, ”3V 1G-BIT SERIAL SLC NAND FLASH MEMORY WITH DUAL/QUAD SPI BUFFER READ & CONTINUOUS READ”, Publication Release Date: May 09, 2018 Revision L

[**37**] NXP Semiconductor, ”SC18IS602B I2C-bus to SPI bridge”, Rev. 7 — 21 October 2019

[**38**] Maxim Integrated, ”MAX30205 Human Body Temperature Sensor”, 19-8505; Rev 0;

[**39**] Molex, SlimStack Board-to-Board Plug, 0.35mm Pitch, SSB RP Series, 1.00mm Mated Height, 2.00mm Mated Width, 6 Circuits, Armor Nail

[**40**] Samtec, Through-hole micro header, (1.27 mm) .050” PITCH FTSH SERIES.

[**41**] Mill-Max, 855-22-006-30-001101 Datasheet, 2018.

[**42**] Medical Alert Advicer, The Future of Medical Wearables: 2022 and Beyond.

[**43**] Doc Wire News, ”5 New and Emerging Wearable Medical Devices”, 2019