This document deals with the theoretical, technical, design and mechanical aspects required for the design and implementation of a system for the characterization of automotive LEDs. The project has been performed as a Bachelor Thesis to finish the studies of Industrial Electronics Engineering at the University of Granada,Spain.

Francisco José Gámez Porcel is the author of this Bachelor Thesis.During these years he has been participating in some GranaSAT projects.His passion for the automotive sector from an early age has led him to choose this project focusing on guiding his professional career in this field and at the same time orient it to the production for this industry.

Andrés María Roldán Aranda is professor in the Department of Electronics and Computer Technology at the University of Granada.
He is the tutor of this bachelor's thesis as well as the academic head of GranaSAT, the aerospace group at the University of Granada.

BACHELOR THESIS

DESIGN AND IMPLEMENTATION OF A CHARACTERIZATION SYSTEM FOR AUTOMOTIVE LEDS

Francisco José Gámez Porcel

2019 2020

UNIVERSITY OF GRANADA
ELECTRONIC ENGINEERING
BACHELOR'S THESIS

Design and implementation of a characterization system for automotive LEDs

Francisco José Gámez Porcel

2019 / 2020

Tutor: Andrés María Roldán Aranda

“Design and implementation of a Characterization System for Automotive LEDs´´

ELECTRONICS ENGINEERING

"Design and implementation of a Characterization System for Automotive LEDs"

CURSO 2019 / 2020

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DEPARTMENT:

Electronics and Computer Technology

Francisco José Gámez Porcel, 2019

🄯 2019 by Francisco José Gámez Porcel: *"Design and implementation of a Characterization System for Automotive LEDs"*

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Design and implementation of a Characterization System for Automotive LEDs

Francisco José Gámez Porcel

KEYWORDS:

Automotive, Vehicle, Headlight, Backlight, LEDs, PCB, Design, Implementation, GRANASAT, Luxometer.

SUMMARY:

The main purpose of this document is the study, design and implementation of a system capable to measure different parameters referred to the light intensity of an LED directly linked to the process of manufacturing it and its power system. This document has been done as a *Bachelor Thesis of Electronics Engineering* in the University of Granada,Spain.

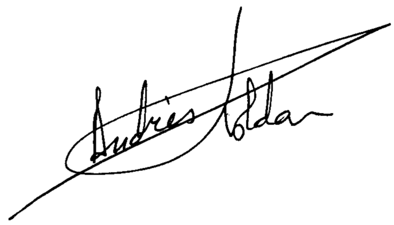
D. Andrés María Roldán Aranda from Electronics and Computers Technology department of the University of Granada, as a proyect manager of the Bachelor Thesis of D. Francisco José Gámez Porcel.

Report that the present document, titled as:

"Design and implementation of a Characterization System for Automotive LEDs"

has been done and redacted by the previous mentioned alumn under my supervision, and at the following date I authorize it's presentation.

Granada, of November of 2019



Fdo. Andrés María Roldán Aranda

The undersigned authorize the present copy of *"Design and implementation of a Characterization System for Automotive LEDs"* to be located in the department library to be free consulted by people that deserve it.

Granada, of November of 2019

Sgd. Francisco José Gámez Porcel Sgd. Andrés María Roldán Aranda

UNIVERSIDAD DE GRANADA

ELECTRONICS ENGINEERING

"Design and implementation of a Characterization System for Automotive LEDs"

PERFORMED BY:
Francisco José Gámez Porcel

DIRECTED BY:
Francisco José Gámez Porcel

THE COURT CONSTITUTED BY:

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Final mark:

☐ Merit (9 - 10 mark)
☐ Good (7 - 8.9 mark)
☐ Pass (5 - 6.9 mark)
☐ Suspense

Final mark: .

Presented in Granada, on November 2019
Evaluated in Granada, on November 2019

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From success, you learn absolutely nothing. From failure and setbacks, conclusions can be drawn. That goes for your private life as well as your career.

Niki Lauda, 1949-2019

Acknowledgment:

First of all, I would like to thank my family, who despite everything has always been by my side offering me a foothold whenever I needed it. Thank you really, for teaching me to value every little progress in my career and never give up.

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Finally, I would like to thank my lab partners from both the University and GranaSAT. I would especially like to thank Luis Sánchez who has managed to provide a touch of professionalism and support in any area of the project that requires it.

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Chapter 1

Motivations

The present project has been carried out as a final bachelor thesis to finish the universal studies of Industrial Electronic Engineering. Personally I was excited to carry out this project because it was a way to focus my personal career towards the automotive world. As we know, it is one of the sectors where electronics are being exploited and therefore it is one of the sectors where we can find more professional opportunities. In addition to this, the passion and entertainment produced by the automotive and motorcycling industry from an early age have pushed me to want to develop my skills in this field. This leads to the fact that by combining skill with passion, you may have developed this work with the necessary desire.

This work in particular allows me to exploit my knowledge in the main aspects of electronics, touching almost all the areas developed during the bachelor's degree. In other words, we talk about product design, product manufacturing, programming, digital electronics, power electronics, electronic instrumentation, etc. At first I knew it was a project that was going to be a plus of dedication due to all the areas that were developed, but once the project is taking shape and results are obtained, personally, it produces enormous satisfaction.Next, all the phases that have been carried out to carry out this project will be detailed.

Chapter 2

Customer requirements

We have previously defined the basis of our project. As we have said, it is focused on its serial production for companies since our product would be fitted as a device for testing in the development phase of automotive products.

For the realization of this project, the multinational company Valeo has been assisted, which has supplied the automotive LEDs to calibrate the device.

Figure 2.1 – *Valeo company logo*

After an analysis to determine what the use of this product will be, the following list of customer requirements has been reached.

⇒ First of all the product must be portable and lightweight.

⇒ It has to be used for different LEDs with different lighting capabilities.

⇒ Must have low consumption.

⇒ It has to be intuitive.

⇒ The data that is sampled can be saved.

⇒ A conventional charger will be used to recharge the product's battery.

⇒ It has to be comfortable when using it.

⇒ You will not need excessive preparation for use.

Chapter 3

System Requirements

As in every phase of development within the engineering of a product, based on established customer requirements, some system requirements are defined, which are what our system will have to meet to meet all customer needs. In this project we will divide the requirements into three classes: mechanical requirements, hardware requirements and software requirements.

3.1 Mechanical requirements

Within the mechanical requirements we take into account everything related to external structure of the system, form of protection of the elements, mechanical form of the system and the different mechanical subsystems that will make up the final system. Meeting all the mechanical requirements in a list:

⇒ We must build two subsystems: the main system that will house the processor and other elements related to data processing and system adjustment; and a tool that will carry the sensors inside.

⇒ Each of these elements must be able to be taken with one hand to facilitate its use in conditions of little space or accessibility.

⇒ The main system must be packaged in a shock-resistant case that can be received during use and that, as far as possible, prevents dust from entering.

⇒ The main system must be ergonomic enough to be controlled by a single person, that is, one hand to hold the device and another to interact with it.

⇒ The main system should have a screen to show the measurement data in real time, as well as to make its use more interactive.

⇒ As the main element of interaction on the device we will use one or more buttons depending on the needs studied in the analysis phase.

⇒ Both the main system and the sensor tool must be able to disconnect from each other to take up as little space as possible.

⇒ The system should be as easy as possible for easy assembly to expedite its serial production.

3.2 Hardware requirements

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As far as hardware is concerned we will list all the elements that we consider necessary to be able to meet the functional requirements of the client.

⇒ The system must have a screen to display the data.

⇒ To control the devices you have to carry a button / button or several.

⇒ As we want to record the data, we will need a system to be able to save the data in an SD or microSD memory.

⇒ To be able to disconnect the tool with the main system sensors, we will need two connectors, one male and one female.

⇒ As we want the system to be portable we have to power it by a battery.

⇒ The fact of introducing a battery imposes on us the need to introduce a charging system and another to adapt the power of the battery to which the system uses.

⇒ The system must be controlled by a processor, in our case we will start using a microcontroller implemented on a pcb.

⇒ For the tool with the sensors we will need more than one sensor to be able to form an indoor device that can give us a more reliable measurement.

⇒ We must have a device capable of maintaining the system at all times at the appropriate date and time.

3.3 Software requirements

To control all the hardware that our product carries, we must use software that meets the following characteristics:

⇒ That the program is correctly organized in menus.

⇒ We must take into account the use that will be given to the device to design a correct state machine.

⇒ To fully exploit the functionalities of the sensors, all of its internal parameters must be adjusted.

⇒ Among the different menus you have to distinguish different sections focused on different defined functionalities.

⇒ A system capable of saving data must be programmed together with a correct date and time record.

3

Chapter 4

System Analysis

4.1 Introduction

Due to the advancement of the automotive sector and the devices used in it, it was thought that it was a good option to work on a device in this area to further deepen knowledge and skills in this sector.

Throughout the entire project the different phases will be carried out:

• Design of a system that allows us to characterize the sensors using automotive LEDs.

• Design of the hardware and case part of our project, as well as the study of each of the devices separately.

• Implementation of a program that allows us to control and adjust our device for each operating condition.

• Construction of the device with commercial materials. Focusing this on its serial production.

• Integration of both hardware and software to present a functional, ergonomic and intuitive final device.

4.1.1 State of Art

Nowadays we can observe the great changes that the world of the automotive sector is undergoing continuously, this implies the ingración of the last technologies in terms of security efficiency and innovation. In the section that refers to lighting the most used as a source of lighting is the LED due to its size, capacities and efficiency. This allows different manufacturers to make designs capable of dividing an illuminated area into different sections as is done with MatrixLED technology. The latter requires that all LED devices have the same illumination characteristics so as not to deform the area that is illuminated. For this, different sensors capable of measuring illuminance, simulating the response of the human eye to these lighting sources are used during development. Getting an exactly calibrated sensor is difficult and expensive for companies. Therefore, in this project a process of characterization of the latest automotive LEDs will be carried out to determine the position of five sensors that will build a better approximation of the real lighting characteristics of each LED. In addition, a portable device will be built in order to facilitate companies the detection of relative differences between different LEDs that are supposed to be the same and are in the same conditions of use but give a different response.

4.1.2 History of lighting systems of automotive industry

The first vehicles had the same lighting capacity as a candle. This was due to an use of an oil candle as a lighting system. 1905's Cadillac was one of the first cars using this lighting system. We can see a photography of it appearance in the next image.

Figure 4.1 – *Cadillac 1905. [1]*

Later the bulb lights arrived as we know it, but the lighting was considerably low. In 1939 appeared the first blinking lights because they started to be considered an important part of the car. In 1962 was the introduction of the first halogen lights and it increased the light output for the same given power consumption of an incandescent light bulb. Taillight was introduced at the same tame in EEUU but it was in 1980 when it uses increased. In 1991 started a new era in vehicle lighting: The Xenon light.

Figure 4.2 – *Xenon bulb. [2]*

The luminous flux of this type of light system tripled the light performance from 1000lm to more than 3000lm. The visibility range increased to 125m in low beam and 250m in high beam. It was traduced in an improvement of the safety conditions on night time driving. Finally, we get to the LED lights, the latest technology. One of the first model that incorporated the LED lights was the Lexus LS600h.

Figure 4.3 – *Lexus 600H. [3]*

The Lexus used LED technology for position and low beam but the Audi R8 was the first vehicle to use LED technology for al lighting functions.

Figure 4.4 – *Audi R8.* [4]

4.1.3 Actuality and future of automotive lighting

LED technology provides a lot of benefits such a low power consumption, low heat emission, longer life, it produces sharp and bright light, and better shock resistance. LED headlights offer longer visual range than xenon headlights and in fog and precipitation it produces less glare. One of the main characteristics of LED lights is that they are maintenance-freee and they are designed to last the life of the car. Combining these features with the sharpness of this type of systems appeared the Matrix LED headlights.

Figure 4.5 – *Opel Astra Matrix LED.* [5]

Matrix LED headlights produce the high beam with tiny light-emitting diodes that are bundled in common reflectors or lenses. The main purpose of these headlights is that they illuminate the road superbly without blinding other road users.

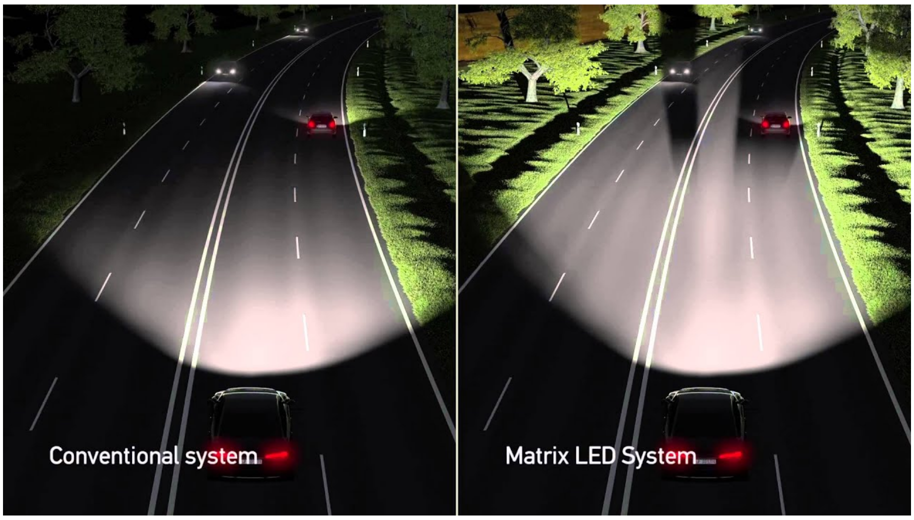

Figure 4.6 – *Headlight comparation [6]*

The most advanced use of this type of lighting is the recently known Pixel LED that has more LEDs in the same amount of area than MATRIX LED technology, traduced into a better resolution of the light emitted. We can compare the main differences between these technologies in the next following image.

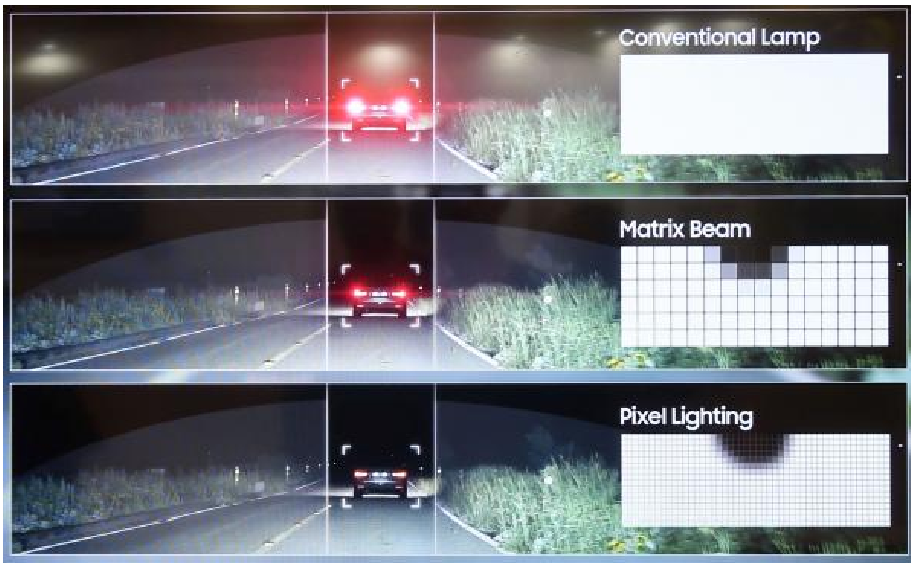

Figure 4.7 – *Samsung Pixel Headlight [7]*

The advantages of these last technologies allow to develop new features focussed on security and driver assistance like pedestrian advisory, animal detection and lighting in low visibility situations.

The combination of these technologies fight a battle against the recently developed LASER light systems. One of the main advantage of a laser lighting is the amount of light you can get of a single device. At high current densities laser diodes operates at much higher efficiencies then LEDs.

Figure 4.8 – *Headlight [8]*

4

4.1.4 Objectives

One of the main purpose of this project is to measure the amount illuminance emitted by a LED diode. The actual situation defined by the high illuminance needs of the LED diodes used in the vehicles systems make not possible to measure the differences between two or more led devices at simple view with human eye. It can be very dangerous and harmful for the eye health. The actual situation makes very important that all LED devices integrated in the same system emit the same illuminance. In Matrix and Pixel LED technologies two devices powered at the same conditions but responding with different lighting characteristics produces a distortion of the image emitted by the whole lighting system. Because of this, and due to customer's requirements, there's a need for measure this illuminance and avoid the difference between two same devices.

4.1.5 Viability

This project has been carried out thanks to the combination of the followings elements listed below: -To the installations and facilities provided by the University of Granada. -The samples of LED devices provided by the company Valeo. -The support and supervision of Andrés Roldán Aranda. -Thanks to all my laboratory's mates and facilities provided by GranaSat.

4.1.6 Development and structure of the project

The development of this project has had the following stages.

-Stage 1: Test and how does it work-understanding of the first prototype of the product done by Sergio Juan Valero Esturillo.

-Stage 2: List of the customer requirements and parts of the previous prototype to be updated or added.

-Stage 3: Modifying of the PCB v1 for fix the problems or adding new features needed for the correct working of the final device. At the same time reprogramming the device to take advantage of these new features.

-Stage 4: Analysis of each of the subsystems.

-Stage 5: Construction of a system that allows us to characterize a sensor based on a certain angle and a certain distance from the source of illumination.

-Stage 6: Characterization of the sensors for creating the new model of the measuring bell device and fit in the correct disposition the five sensors.

-Stage 7: Simulation of the PCB v2 appearance with all the new devices added with Altium and export to SolidWorks for verifying that all components fit in.

-Stage 8: Physical construction of the systems and assembly of components.Device programming.

-Stage 9: Verification of the correct functioning of the system and analysis of results.

4.2 Light Measurement

4.2.1 What is the light?

Light is just one portion of the various electromagnetic waves flying through space. The electromagnetic spectrum covers a huge range , it goes from radio waves with a meter wavelength to x-rays with less of a billionth of a meter wavelengths. The optical radiation takes a range between these wavelengths.

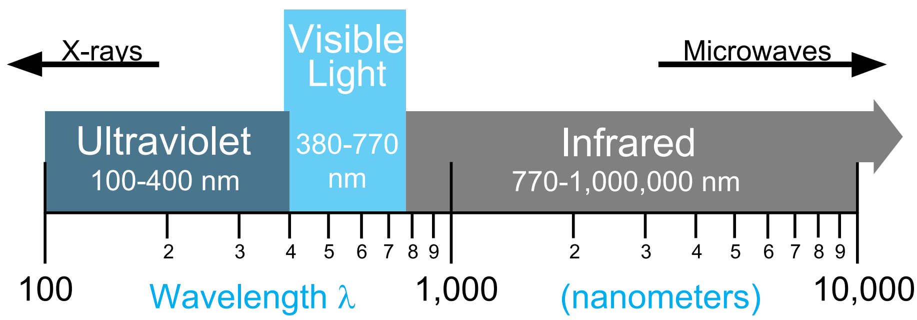

Figure 4.9 – *Electromagnetic spectrum [9]*

We can model light as a ray traveling in a straight line, which can be redirected along predictable paths with lenses and mirrors. Looking at the previous diagram we can distinguish three types of light. On left side we find ultraviolet light which travels from 10nm to 400nm wavelengths. Short wavelength UV light exhibits more quantum properties than its visible and infrared counterparts. Ultraviolet light is arbitrarily broken down into three bands, according to its anecdotal effects.

UV-A, often called black light, is the least harmful and most commonly found type of UV light, because it has the least energy.

UV-B is typically the most destructive form of UV light, because it has enough energy to damage biological tissues, yet not quite enough to be completely absorbed by the atmosphere. It can cause skin cancer.

4

UV-C is almost completely absorbed in air within a few hundred meters due to a collision between photons and oxygen atoms causing the formation of ozone. Visible light is found from 380nm to 770nm wavelengths, it is by far the part of the light that interest us for this project. The colour we perceive is composed by three components: hue, saturation and brightness. The product of these components can be model as a sphere as we show below.

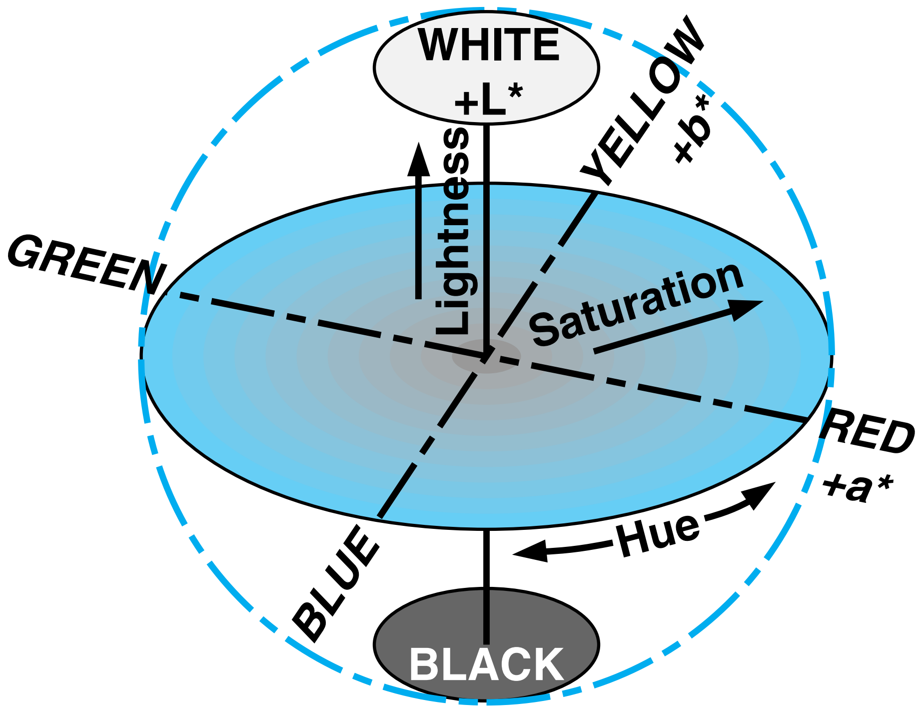

Figure 4.10 – *Color-Space sphere* [9]

On the other side of electromagnetic spectrum, we can find infrared light. This type of light includes wavelengths from 770nm to 1.000.000nm. It's characterized by content the least amount energy per photon. This range of electromagnetic spectrum is also important in our project how we can see in the next chapters.

4.2.2 Basic concepts of light measurement and measurement geometries

Before we start working with light unis, and parameters let´s define the following concepts.

-*Photometry* is concerned with the measurement of optical radiation that is perceived by human eye.

-*Radiometry* is a set of techniques for measuring electromagnetic radiation, including visible light.

Radiometric techniques in optics characterize the distribution of the radiation's power in space, as opposed to photometric techniques, which characterize the light's interaction with the human eye.In radiometry, irradiance is the radiant flux (power) received by a surface per unit area. The SI unit of irradiance is the watt per square metre (Wm^2).

4

4.2.3 Basic principles

Inverse Square Law

When we measure the irradiance from a point source we have to keep in mind the influence of the distance. Thanks to the Inverse Square Law we can stablish a relation between the distance and the intensity per unit of area that hits a surface.

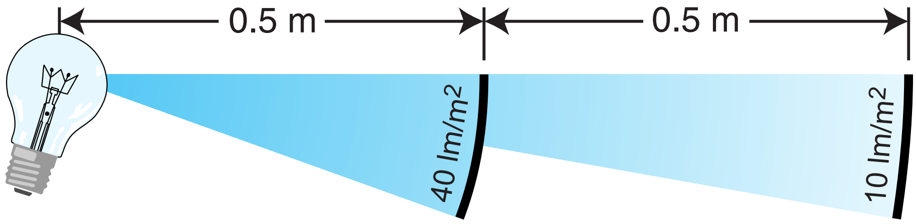

Figure 4.11 – *Inverse square law [9]*

In this diagram we can see that is very important to set de distance from the first luminating surface.

The following equation sets the relation between the different magnitudes.

$$E = I/d2 \tag{4.2.1}$$

Lambert´s Cosine Law

The irradiance or illuminance falling on any surface depends on the cosine of the incident angle. The next figure shows what amount of incident flux is received for the surface with a determinate angle.

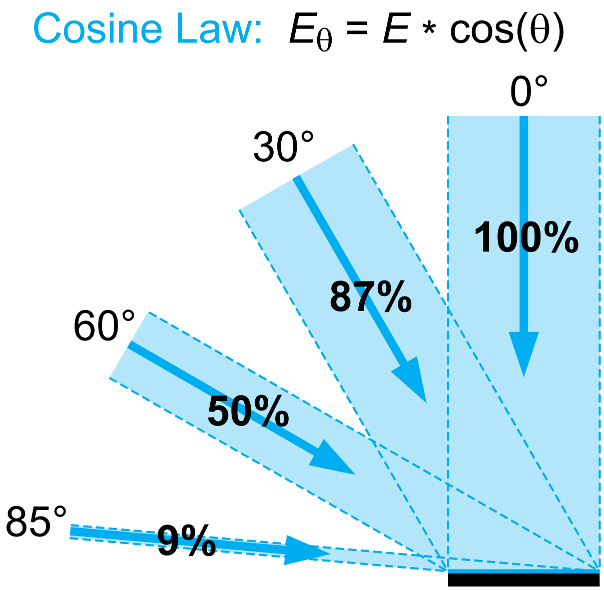

Figure 4.12 – *Lambert's cosine law [9]*

Lambertian Surface

A Lambertian surface is defined by the uniform difussion of the incident radiation which has the same radiance or illuminance in al directions.

The next figure shows a surface radiating equally from 0° to 60°. A radiance detector must see twice as much surface area in the same solid angle for the 60° case.

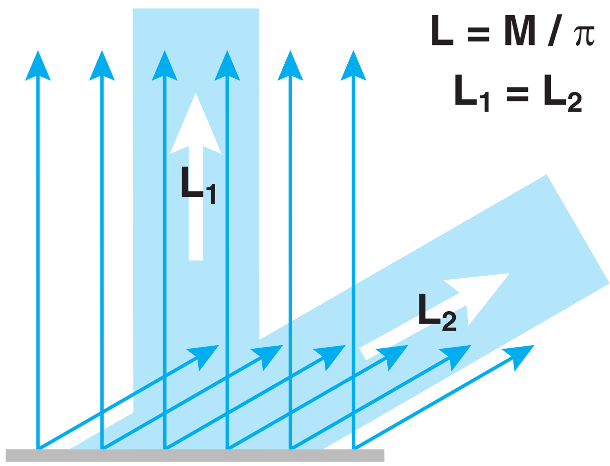

Figure 4.13 – *Reflected Lambertian surface [9]*

A reflection from a Lambertian surface obeys the cosine law by distributing reflected energy in proportion to the cosine of the reflected angle

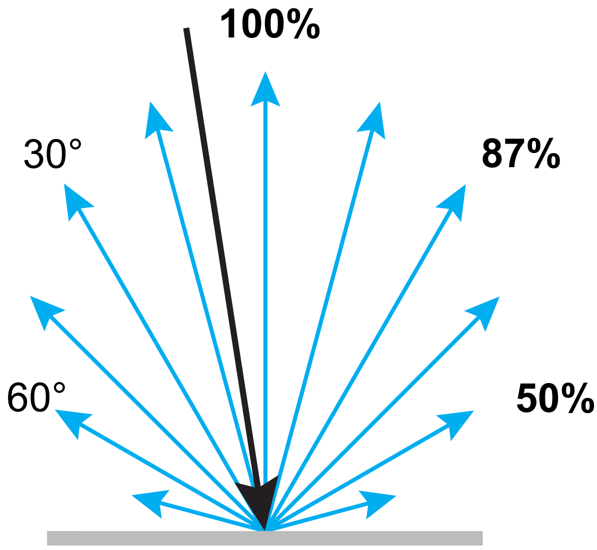

Figure 4.14 – *Puntual reflected Lambertian surface [9]*

This is very usefull to our project beacuase the source that we are going to use emits it radiation as a Lambertian surface. We will see that in the next chapters.

4.2.4 The LED as a light source

A LED (*Light Emitting Diode*) is a semiconductor that emits light when current flows through it.The internal process is determined by the recombination of electrons and holes of the semiconductor that releases energy in the form of photons.The colour of the light is determined by the energy required for electrons to cross the band gap of the semiconductor.

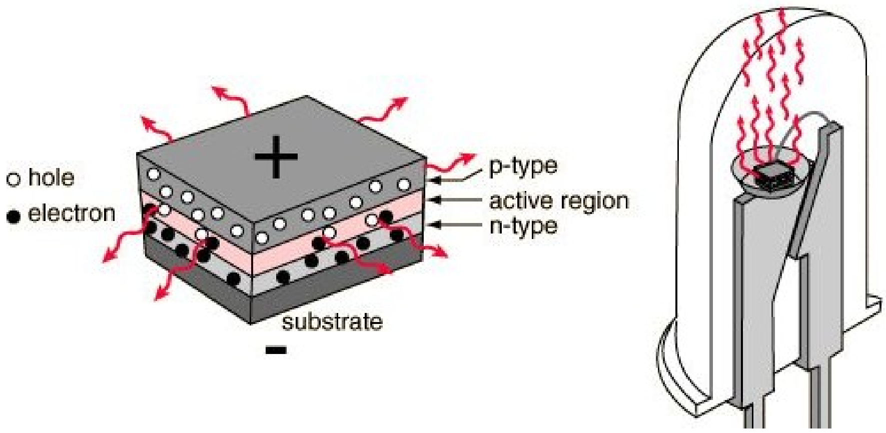

Figure 4.15 – *LED structure*

LEDs have many advantages over other types of light sources, it involves a lower energy consumption, smaller size, better physical robustness, loger lifetime and faster switching. Due to this characteristics they could be used in many aplications such as aviation lighting, automotive lighting, camera flashes, advertising, medical devices etc.

The first LED was discovered in 1961 by James R.Biard and Gary Pittman.They created a tunel diode and placed it on a GaAs substrate discovering that there's light production during forward bias operation.

After that the LED has been continuously developing, improving its capabilities and lowering its costs.

Actually we can find a diverse variety of LED devices.With the passage of time new technologies are discovered. The latest technology developed is OLED technology.

The OLED(Organic LED) technology is made from a layer of organic electroluminiscent material which p/n junction is between electrodes. At least, one of them is transparent so the photons can scape.This technology provides many advantages such the reduced size and improved energy efficiency, but it still producing less lumens than a normal LED.

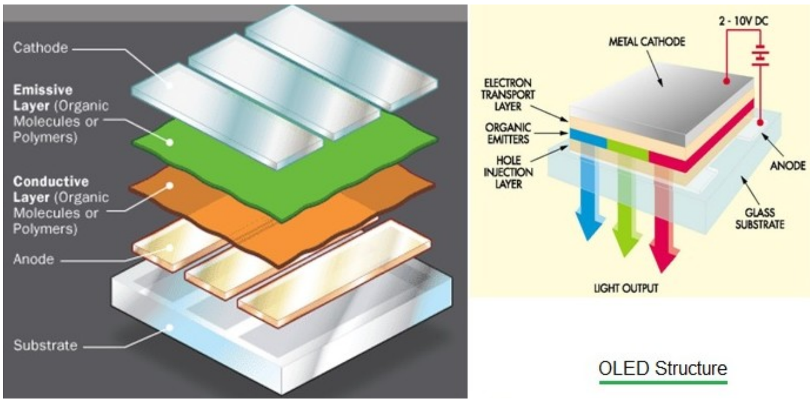

Figure 4.16 – *OLED structure [10]*

In this project we are going to focus on SMD LEDs, which ones are being used in the last automotive technology.

4.2.5 Automotive LEDs

There are three main types of car lighting. These are halogen, HID (High-Intensity Discharge lights) and the LED lights. Comparing these diferents types we find that halogen lights are less efficient than LEDs and also less durable. HIDs were the brightest ones but it were larger than a LEDs making more difficult to control them than the LEDs.

Not all the characterictics of a LED are advantages, there are also contras like the heat disipation. It´s one of the main issue of this type of lighting.

The main reason to this heat disipation is the use of drivers to bring the appropiate power to the LED. The figure above shows an example of LED lamps for replacing conventional lights with them.

Figure 4.17 – *Aftermarket LED bulbs [11]*

As we can see under the LEDs it's placed the driver which needs a dissipator to evacuate excess heat produced.

Last developed series vehicles already include SMD LEDs directly integrated in the lighting system.

These LEDs are increasingly powerful, increasing efficiency and greatly improving the performance of vehicle lighting systems.

If you look at the latest LEDs on the market, due to the light power they have, it is very difficult to appreciate, with the limitations of the human eye, differences between two LEDs that apparently illuminate the same.

The market's need to use these LEDs to integrate them into the latest lighting systems developed such as the Matrix LEDs or the Pixel LEDs mentioned above, makes very homogeneous systems as far as lighting is needed.

Therefore, it is very useful to develop this project to be able to appreciate those differences that we cannot see at first glance but which, when combined with optical systems, can cause great distortions.

4.3 Schedule

4.3.1 Chapter description

This section will briefly describe what is done in each chapter:

▶ Chapter 1: This chapter analyzes the main purposes of the project and what has prompted me to choose this project and to be able to finish it correctly.

▶ Chapter 2: the needs of the client are analyzed.

▶ Chapter 3: We pass from the customer's requirements to the requirements of our project in order to meet the objectives of the client's needs.

▶ Chapter 4: It is analyzed based on the established requirements, what devices and what technology will be used to build the final device.

▶ Chapter 5: we make a first approximation of how our device will be and what subsystems it will have.

▶ Chapter 6: in this section a system is constructed to characterize one of the sensors that we will use in the final device and its characterization is carried out.

▶ Chapter 7: The final system is designed by choosing each module separately, and the software that will control it is also designed.

▶ Chapter 8: All components are manufactured and assembled.

▶ Chapter 9: once we have the device ready we verify that the results are verified.

▶ Chapter 10: the results obtained are discussed and possible future projects are studied using this as a basis.

▶ Chapter 11: global project budget.

4.3.2 Temporary planning

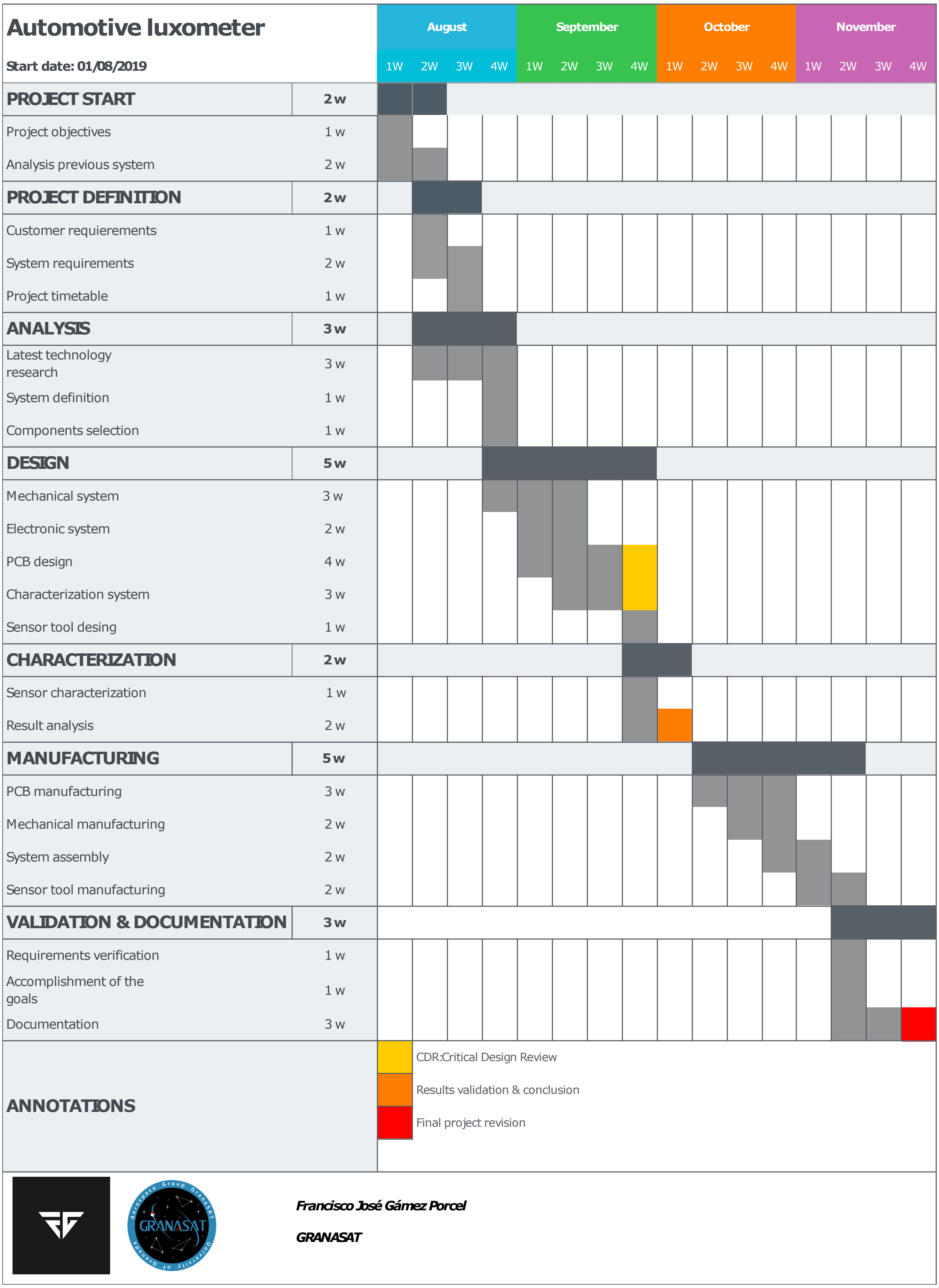

Figure 4.18 – *Gantt's diagram*

Chapter 5

Design

The main purpose of this chapter is to describe how both the physical part and the electronic part of the project have been studied taking into account different aspects related to the use and manufacture of the same.

The main idea is to make a system in which we differentiate two subsystems interconnected by a wiring that can be disconnected.

These subsystems will be:

→A tool with the sensors housed inside.

→A device in which the rest of the necessary circuitry is found with an interface to communicate correctly with the customer.

5.1 Mechanical System

5.1.1 POC of the case

When we first think about the case shape we decided that it would need to be a compact product that could be taken with both hands, one to hold the device and the other to navigate and interact with the different interfaces, something similar to what we would do with a mobile phone.

The figure below shows the first POC of the idea.

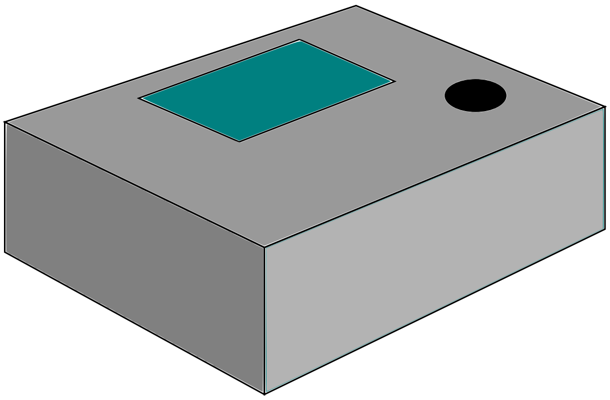

Figure 5.1 – *POC of the case*

This idea had to be modified in the next chapters in order to adapt the necessary electronic devices.

5.1.2 POC of the sensor tool

5

As we have seen in previous chapters, our sensor tool will consist of five sensors inside, distributed in the form of a bell. When designing it, you have to think about both utility and ergonomics since the client will interact directly with it.

For this reason, it has been decided to make the bell with the following initial form:

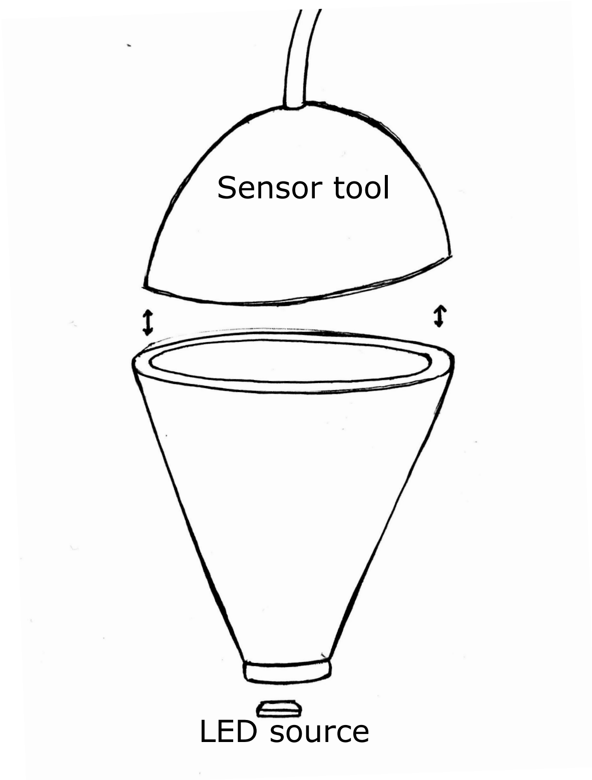

Figure 5.2 – *POC sensor tool*

5.2 Electronic Devices

Based on the customer requirements it was generated a list with the necessary componets for the properly operation of the device:

→ LCD Screen

→ Rotary button

→ Micro SD Card Reader

→ Charging plug

→ Programmation plug

→ On-Date and time device

→ Sensor

→ Sensor Plug

→ Mainboard

→ Micro-controller

→ Battery

→ Battery-charger device

5.3 Design conclusions

Once studied the possibilities of each system and established a way to assemble all the components to integrate a final system that meets the customer's requirements, the following conclusions have been obtained:

• In principle, an Arduino Mega will be used as a microcontroller due to the number of available pins, which we will use to connect the different devices that make up our system.

• Due to the connection of the components and taking into account the connection standards, a USB Type A cable will be used as a way of connecting to other devices.

• Due to the use of a battery charging module and the integration of a microcontroller which is programmed through a port that will work at the same voltage, the same port will be used to program the device and to charge the battery.

• A LiPo battery will be used compact enough to integrate it into the system case, it will provide a 3.7V potential.Therefore, it will need a converter device to increase the working voltage of the microcontroller 5V.

- As a way to control the device, a single rotary circular button will be used with which you can navigate through all the functions that the system offers

- Due to the working conditions a sufficiently insulated case will be provided with special attention to the protection of the screen which we will need as an interface to show the measurements.

Chapter 6

Sensor analysis and characterization

In this chapter the following topics will be discussed:

▶ The study of the sensor that we will use for our tool to know what characteristics of it we can take.

▶ The design and implementation of a system that allows us to know how our sensor works and how we can use it.

▶ The implementation of a code for use in the measurement system.

▶ A measurement procedure to test with LEDs for automotive.

▶ Solutions will be identified based on the results of the measurement procedure.

6.1 Use of the sensor

The sensor to be used will be the TSL2561. This sensor transforms light intensity into a digital signal that is transmitted through the I2C bus. This device has two photodiodes: one with infrared response and another with visible-infrared response that is encoded in a dynamic range of 20 bits.

Through an internal procedure of the device itself, an integration is made between the measurement of both photodiodes resulting in an output in Lux units that approximate the response of the human eye to this intensity.

In the following figure we can see the different functional blocks that make up this sensor:

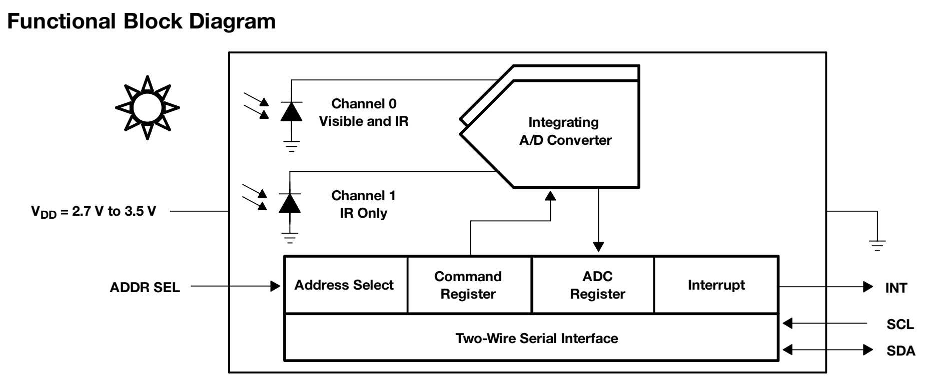

Figure 6.1 – *Funtional blocks of TSL2561 sensor*

This device is powered at 3.3V and it is very important not to exceed this value because it can cause significant damage to the device.

The sensor is implemented in various forms of PCB depending on each manufacturer, the one used in our case has the following appearance:

Figure 6.2 – *TSL2561 sensor*

This packaging has the following connection pins: GND, VCC, SDA, SCL, INT. The latter is used to program the device through interruptions, in this project this feature will not be used.

6.1.1 Addressing the sensor

As we said before this device works through the I2C interface.

Every component attached to an I2C bus has a fixed address from 0 to 127. We can theoretically have a maximum of 128 devices on a single bus, but in practice we are limited to the options available for each part.

The TSL2561 supports three possible addresses: 0x29, 0x39, or 0x49. Which address the part uses is controlled by the solder jumper labeled "ADDR". When there is no solder on this jumper, the TSL2561 will used the default address of 0x39.

To use one of the other addresses, we add solder to bridge the center pad to ONE of the two side pads. If we bridge to the "0" side, the address will be 0x29. If you bridge to the "1" side, the address will be 0x49. ***It´s very important to not bridge both sides.***

6.1.2 Setting the TSL2561

There are two settings you can make to control the sensitivity of the TSL2561.

Integration time

The integration time on the TSL2561 sensor functions as the shutter of a camera, that is, depending on the amount of light to which the sensor is exposed, the shutter aperture can be adjusted, in this case it is done by varying the integration time. The default integration time is 402ms but it can be changed to 101ms and 13.7ms. This means that shorter integration times will allow less light to pass, unlike the longer ones that allow more light to pass through. We will use the latter when the amount of light is less in order to have a higher resolution.

Gain

In addition to the integration time another parameter can be adjusted as we have said before, this is the gain. This can be alternated between two levels: 1x and 16x, which, as we can imagine, has sixteen times the sensitivity of the first. The 1x gain will be used in bright conditions while the 16x gain will be used in low brightness conditions.

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In addition to these two types of gain, it gives us a third option that is Auto gain in which it is automatically adjusted depending on the amount of light received by the sensor.

6.1.3 Converting units from Lux to Lumens

As we have seen previously our sensor samples resulting in illuminance in Lux units. Applying this to the commercial world, most technical data sheets show us data related to the luminous flux (Lumens). This is why we have to do a unit conversion.

First we convert lux (illuminance) to candles (light intensity).They depend proportionally on the distance.

$$I_v = E_v * D^2 \tag{6.1.1}$$

Then we convert taking into account the beam angle to lumens.

$$\psi_v = 2 * \pi * I_v * (1 - \cos(\frac{\alpha}{2})) \tag{6.1.2}$$

Where we denote candles(cd) as

$$I_v$$

Illuminance (lux) as

$$E_v$$

and luminous flux(lumens)as

$$\psi_v$$

In our case, as we will see in later chapters, we will establish a fixed distance and a beam angle of 120 degrees, which is what most LED manufacturers indicate in their datasheet.

6.2 Design of a light measurement system

In this chapter we will proceed to design a system that allows us to sample different measurements in lux units varying the lighting conditions and sensor position. This will be useful for us to design a tool that consists of five sensors for a more accurate measurement and better data acquisition.

6.2.1 First steps and POC

First of all thinking about the system we were looking for two ideas were clear:

- The need to vary the height of the sensor with respect to the source of illumination.
- The need to vary the inclination of the sensor with respect to the point of maximum light intensity.

For the development of this system the following recursive procedure was followed:

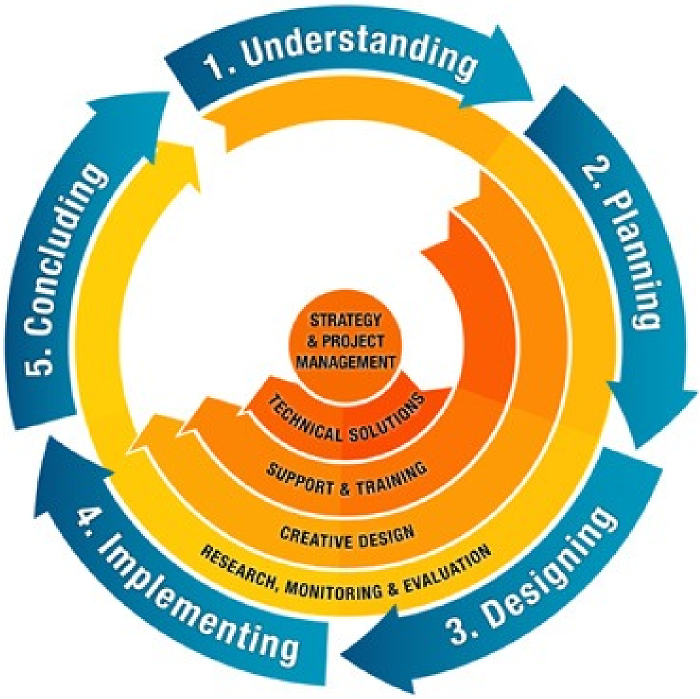

Figure 6.3 – *Cycle of the product development*

With this in mind, the first system in which the sensor could be rotated and adjusted in height was developed.

First sketches were made about the system. Taking into account the dimensions of the sensor module, the mast that held it was made.

The mechanical design was done with SolidWorks and then the different parts of the system were joined, giving rise to the system in the following figure.

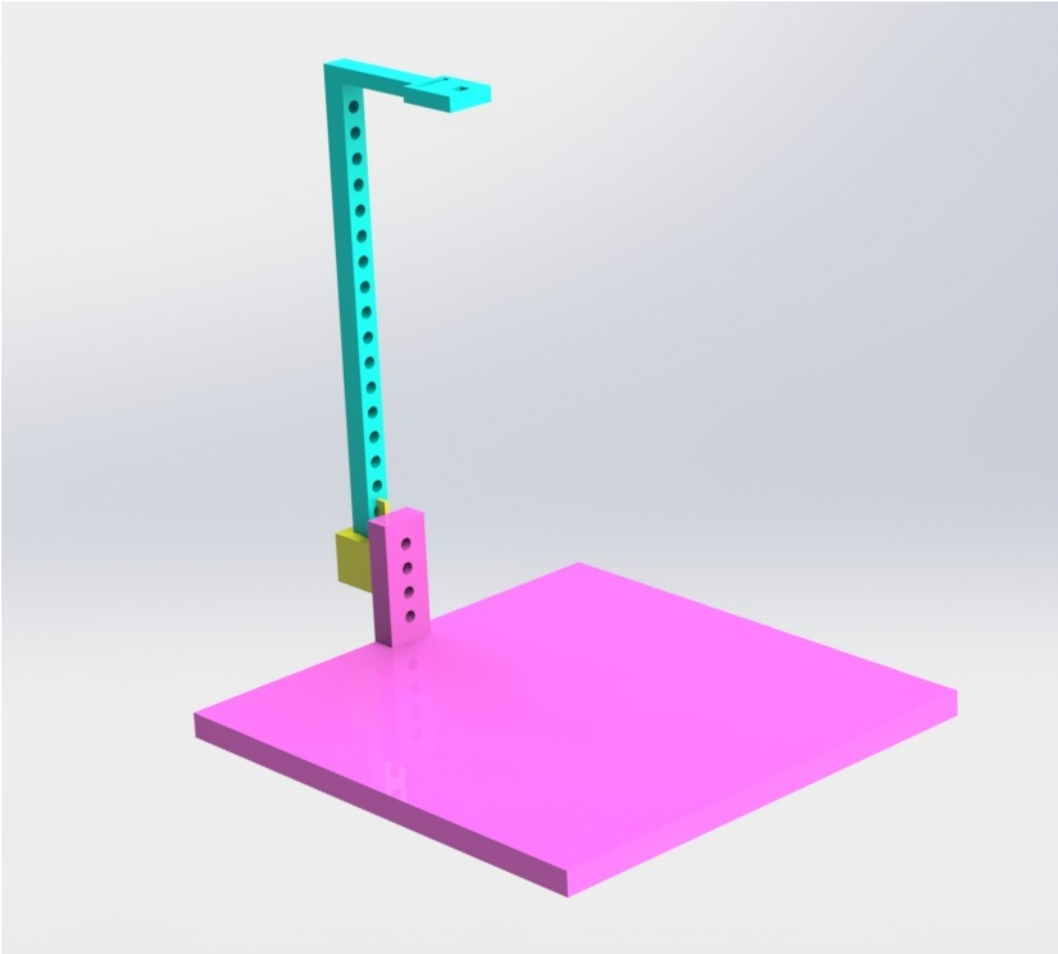

Figure 6.4 – *Fist measurement system design*

The pieces were physically made with 3D printing and after this the sensor was placed as initially thought.

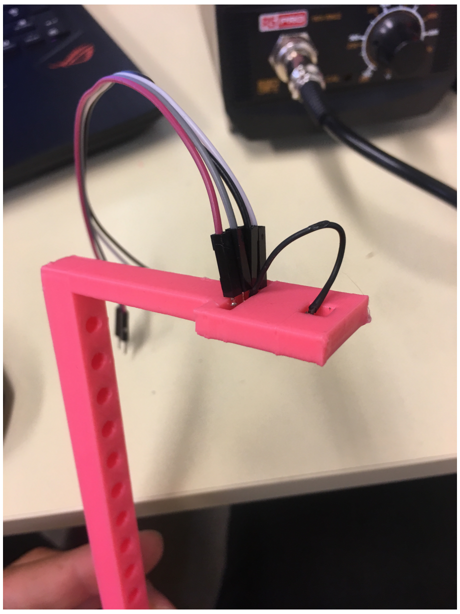

Figure 6.5 – *Fist measurement system with sensor(Top view)*

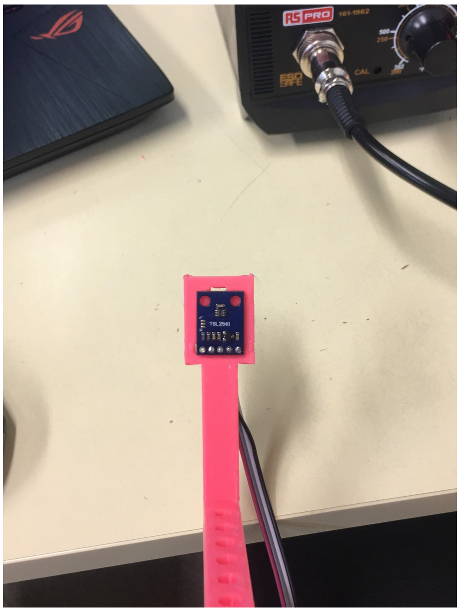

Figure 6.6 – *Fist measurement system with sensor(Bottom view)*

6.2.2 Final design and principal features

After reviewing the system and thinking about possible improvements, the following conclusions were reached:

- The use of a single axis to adjust the entire system meant that we had to disassemble the system every time we wanted to vary the height, which meant a mismatch in the angle.
- We had to add an external system to the one designed to show the angle correctly.
- The sensor did not have a firm grip that would ensure its blockage against any movement.
- The platform limits us to the maximum height that the device carrying the light source could have.

Taking these points into account and correcting some errors due to 3D printing, it was thought to change the base for the following system:

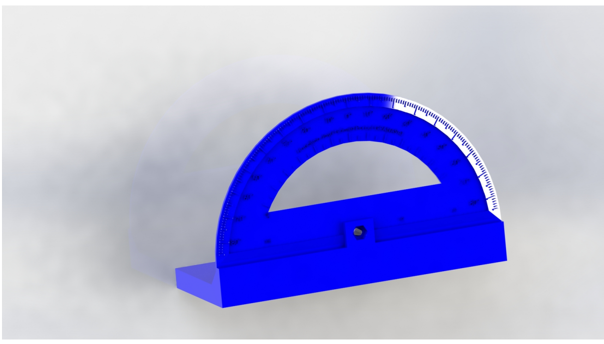

Figure 6.7 – *Base-protractor for measurement system*

Initially it was a good solution but the limitation found was due to the size of the system and the minimum resolution of the 3D printer that limited us when printing the numbering of the angles and did not do it correctly.

After a continuous improvement and analysis of the system, the final solution was reached.

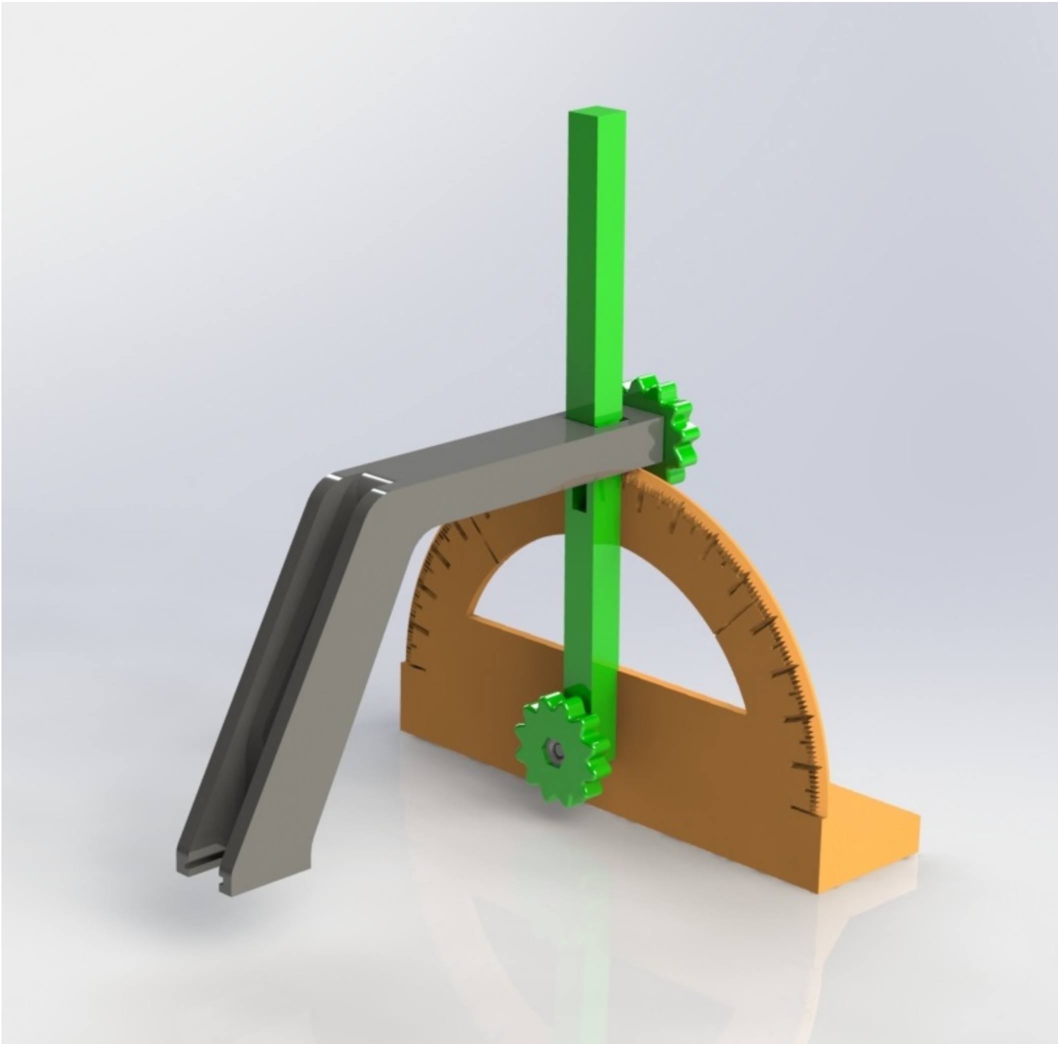

Figure 6.8 – *Final measurement system*

This last system had the following advantages:

▶ The use of cogwheels for manual adjustment of height and angle. This means that you don't have to use different tools.

▶ Greater precision in height adjustment because the adjustment points are unlimited.

▶ No dependence on a defined base, so by adding different plates the height can be adjusted with respect to the position of the LED.

▶ The protractor ,for its type of printing and design, could already be printed correctly.

▶ A precise sensor support was available, so if we decided to alternate different sensors we made sure they are in the same position.

6.2.3 Manufacturing and 3D printing

Once the system has been designed, we must export it from the SolidWorks program in .stl format. This will be the necessary format to load it into the 3D printing program. In our case, the Ultimaker Cura 4.3.0 will be used.

In this program we must configure the necessary print parameters to find a balance between print speed and print quality.

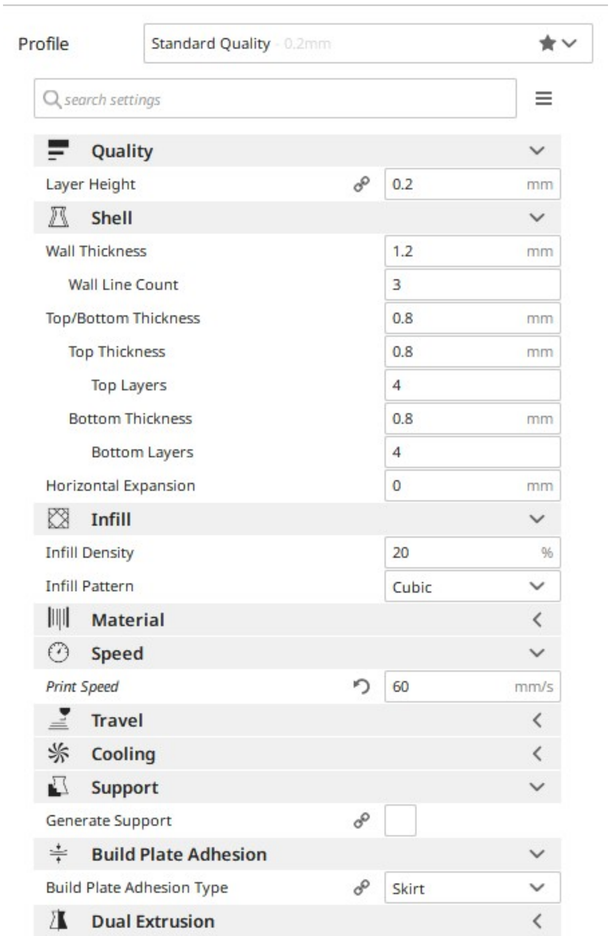

Figure 6.9 – *Ultimaker Cura print settings*

In this project the Creality Ender 3 printer model will be used. In the following image we can see the appearance of it.

Figure 6.10 – *3D Printer Creality Ender 3 Pro*

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Once we import the piece into the Ultimaker we must adjust its position so that it fits so that the smallest possible auxiliary supports are used.

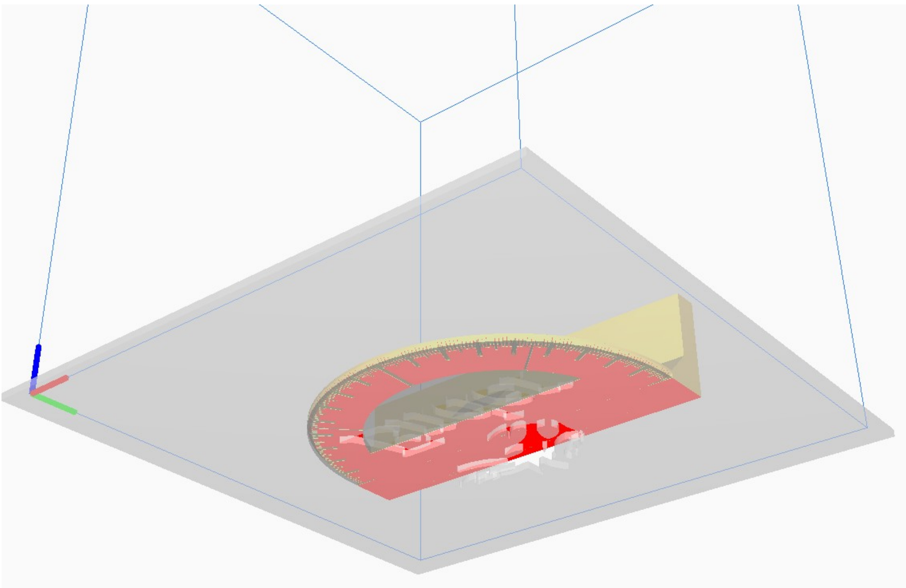

Figure 6.11 – *Bottom view of the Ultimaker Cura interface*

As we can see from having more detail we have put the part with the numbering down because the printer is printing layer by layer up.

Next we will see the result after printing.

Figure 6.12 – *3D Printed protractor*

Figure 6.13 – *3D Printed cogwheel*

Figure 6.14 – *3D Printed mast*

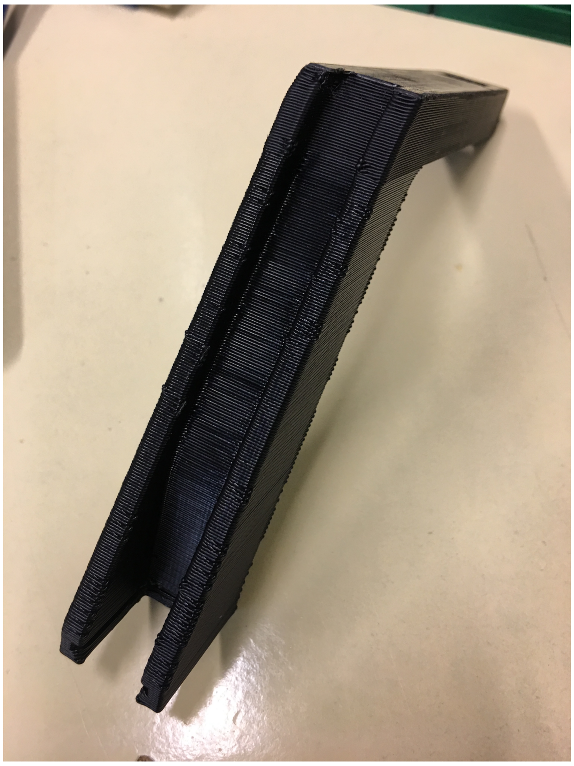

Figure 6.15 – *3D Printed sensor support*

Finally, the complete system was mounted with the necessary screws and one of the brightness sensors was fitted and the wiring was connected.

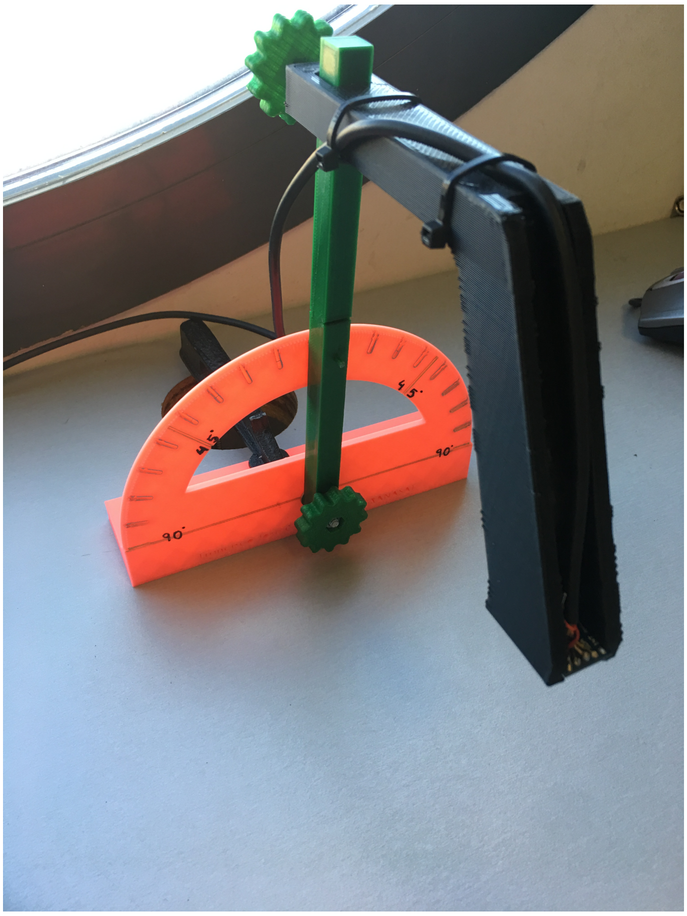

Figure 6.16 – *Fully assembled system*

6.3 Complete system and program

Once we have the system capable of measuring illuminance by adjusting the height of the sensor and the rotation of the sensor with respect to the source of illumination, we have to design a software system capable of monitoring the data received from the sensor. For this, an Arduino will be used through which we will transmit the data through the I2C port and we will vary both the physical parameters of the system and the software parameters of the sensor.

For this, the following program has been created using C ++.

```

//THIS PROGRAM IS DESIGNED TO MEASURE WITH AN ONLY ONE SENSOR
//USING THE PROTRACTOR DEVICE FOR CHARACTERIZATE SENSORS


#include "./Adafruit_Sensor-master/Adafruit_Sensor.h" //
#include "./Adafruit_TSL2561-master/Adafruit_Sensor.h"
#include "./Adafruit_TSL2561-master/Adafruit_TSL2561_U.h"
#include "./Adafruit_TSL2561-master/Adafruit_TSL2561_U.cpp"
```

```
#include <Wire.h>
//Sensors I2C ports

Adafruit_TSL2561_Unified tsl_1 = Adafruit_TSL2561_Unified(TSL2561_ADDR_LOW,
    00001); //Sensor 1

int value=0;

void setup() {
// put your setup code here, to run once:
Serial.begin(9600);
Serial.println("Starting device");
if(!tsl_1.begin()){
Serial.print("Sensor failed to init");}
else
{Serial.println("Sensor init correctly");
Serial.println("---------------------------");
Serial.println("            MAIN MENU          ");
Serial.println("---------------------------");
Serial.println("Press 1 -   Set Gain 1x");
Serial.println("Press 2 -   Set Gain 16x");
Serial.println("Press 3 -   Set Gain Auto");
Serial.println("Press 5 -   Set IT    13ms");
Serial.println("Press 6 -   Set IT   101ms");
Serial.println("Press 7 -   Set IT   402ms");
Serial.println("Press m -   Print measure ");
}
}

void loop() {

if (Serial.available()>0){
value = Serial.read();
delay(5);
//GAIN
if (value == '1'){
Serial.println("Gain 1x");
tsl_1.setGain(TSL2561_GAIN_1X);
tsl_1.enableAutoRange(false);
}
if (value == '2'){
Serial.println("Gain 16x");
tsl_1.setGain(TSL2561_GAIN_16X);
tsl_1.enableAutoRange(false);
}
if (value == '3'){
Serial.println("Gain Auto");
tsl_1.enableAutoRange(true);
//INTEGRATION TIME
}
if (value == '5'){
Serial.println("Integration time 13ms");
tsl_1.setIntegrationTime(TSL2561_INTEGRATIONTIME_13MS);
}
```

```
if (value == '6'){
Serial.println("Integration time 101ms");
tsl_1.setIntegrationTime(TSL2561_INTEGRATIONTIME_101MS);
}
if (value == '7'){
Serial.println("Integration time 402ms");
tsl_1.setIntegrationTime(TSL2561_INTEGRATIONTIME_402MS);
}
//MEASURE
if (value == 'm'){
sensors_event_t event1;
tsl_1.getEvent(&event1);
Serial.println(event1.light);
}
}
}
```

The program will monitor the data received by the sensor through the serial port. The following keys are used to navigate between the different program options:

- Key 1: Set the gain to 1x.
- Key 2: Set the gain to 16x.
- Key 3: Set the gain to Auto mode.
- Key 5: Set the integration time to 13 ms.
- Key 6: Set the integration time to 101 ms.
- Key 7: Set the integration time to 402 ms.
- Key M: Measure.

Next, a methodology will be designed to characterize the LEDs.

6.4 Measurement plan

As we have seen before, the LED emits its radiation in the form of a Lambert surface. Therefore, determining a fixed height, we will vary the angle of inclination of the sensor with respect to the projection perpendicular to the LED, seeing how this variation of the angle influences the measure of illuminance.

Based on the fact that we have to design a real system with a tool that can be grasped by hand to place it on the LED when the measurement is to be carried out, we cannot determine a height too high respect to the LED.

Therefore, it has been concluded that we will vary the height from 0 cm to 6 cm with an increase of 1 cm between the different measures.

Furthermore, in the event that the sensor is saturated for any gain in all its measurements at 0 degrees (maximum illuminance value), the height from which it begins to measure correctly without saturation will be determined.

For the measurement plan, a template such as the following is used to record the data:

Height				
Angle		Integration time		
		13.7 ms	101 ms	402 ms
Gain	1x			
	16x			
	Auto			

Figure 6.17 – *Measure template*

6.5 Light source selection

Once the method for characterization has been defined we need to choose a lighting source whose technical data we know.

In our case we will use LEDs of the OSLON Black Flat family of the OSRAM manufacturer, these LEDs are specially designed for the automotive sector.

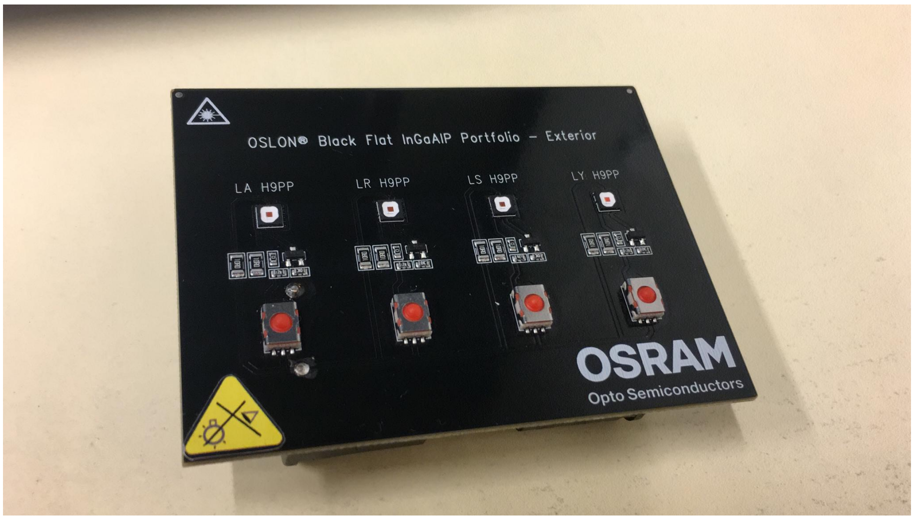

Figure 6.18 – *OSLON Test LEDs*

Among the different products that we can find in this family we will choose the following: OSLON Black Flat LA H9PP.

Below we show the main technical characteristics of this LED:

◦ Package: SMD epoxy package.

◦ Chip technology: Thinfilm.

○ Typ. Radiation: 120° (Lambertian emitter).

○ Color: lambda dom = 617 nm (amber).

○ Corrosion Robustness Class: 3B.

○ Qualifications: The product qualification test plan is based on the guidelines of AEC-Q101-REV-C, Stress Test Qualification for Automotive Grade Discrete Semiconductors.

○ ESD: 8 kV acc. to ANSI/ESDA/JEDEC JS-001 (HBM, Class 3B).

Due to the type of radiation of these LEDs, characterized as Lambertian emitters, both the characterization of the sensor and the design of the sensor tool have been designed for emitters of this type.

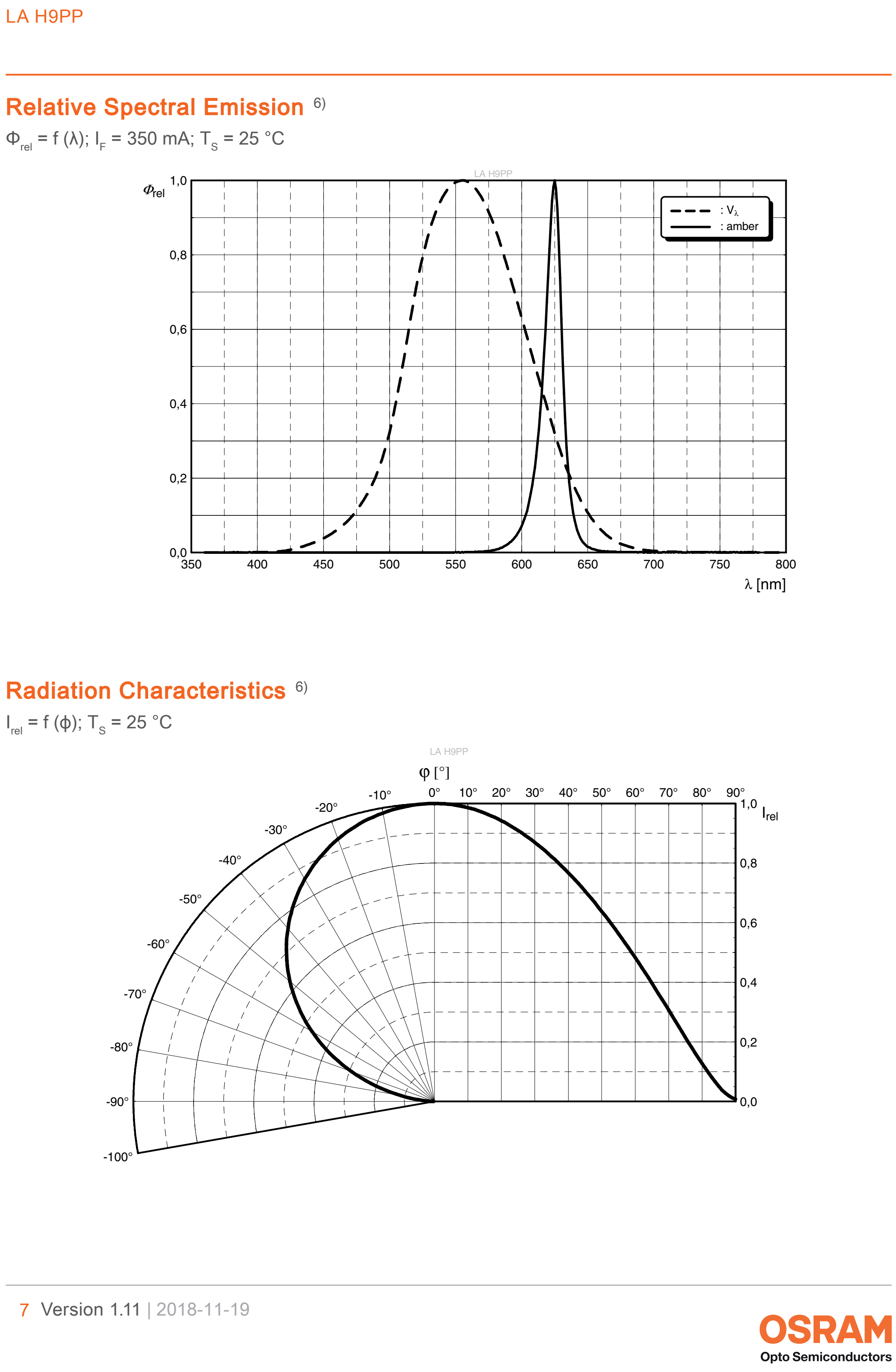

Figure 6.19 – *OSLON LA H9PP EN*

6.6 Results and conclusion

For the measurement method we will use a combination of the following parameters:

- Height: 1 cm, 2 cm, 3 cm, 4 cm, 5 cm, 6 cm.
- Tilt angle: 0°,± 30°,± 45°,± 60°.

The following consumption was obtained at maximum power:

- LED Voltage: 2.082V.
- LED Current consumption: 0.376A.

Figure 6.20 – *LED Power consumption*

Once we have all the parameters correctly defined, we carry out the measurement process.

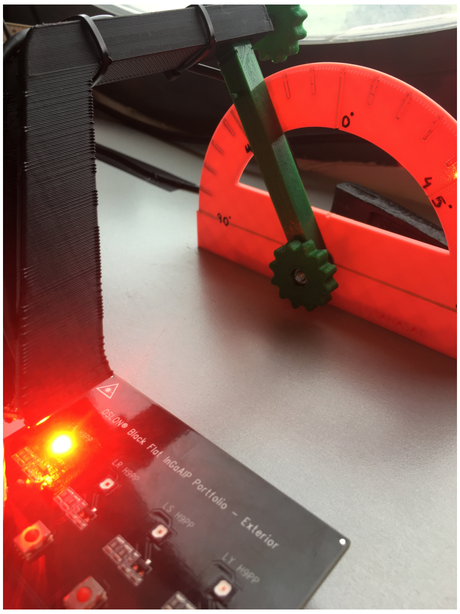

Table 6.1 – *Measurement process*

The following results were obtained:

Height = 1 cm

0		Integration time		
		13.7ms	101ms	402ms
Gain	1x	Sat.	Sat.	Sat
	16x	Sat.	Sat.	Sat.
	Auto	Sat.	Sat.	Sat.

-30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	Sat.	Sat.	Sat
	16x	Sat.	Sat.	Sat.
	Auto	Sat.	Sat.	Sat.

30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	Sat.	Sat.	Sat
	16x	Sat.	Sat.	Sat.
	Auto	Sat.	Sat.	Sat.

-45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	Sat.	Sat.	Sat
	16x	Sat.	Sat.	Sat.
	Auto	Sat.	Sat.	Sat.

45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	Sat.	Sat.	Sat
	16x	Sat.	Sat.	Sat.
	Auto	Sat.	Sat.	Sat.

-60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	Sat.	Sat.	Sat
	16x	Sat.	Sat.	Sat.
	Auto	Sat.	Sat.	Sat.

60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	Sat.	Sat.	Sat
	16x	Sat.	Sat.	Sat.
	Auto	Sat.	Sat.	Sat.

Table 6.2 – *Sensor final measures height=1cm (Lux units)*

Height = 2 cm

0°		Integration time		
		13.7ms	101ms	402ms
Gain	1x	37978	38850	Sat.
	16x	Sat.	Sat.	Sat.
	Auto	37918	38667	Sat.

-30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	35080	35732	Sat.
	16x	Sat.	Sat.	Sat.
	Auto	35055	35743	Sat.

30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	32164	32862	Sat.
	16x	Sat.	Sat.	Sat.
	Auto	32249	32904	Sat.

-45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	29472	30071	Sat.
	16x	Sat.	Sat.	Sat.
	Auto	29699	30293	Sat.

45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	25360	25881	25960
	16x	Sat.	Sat.	Sat.
	Auto	25354	25835	25896

-60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	22829	23285	23344
	16x	Sat.	Sat.	Sat.
	Auto	22839	23295	23337

60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	14981	15277	15310
	16x	Sat.	Sat.	Sat.
	Auto	14996	15287	15323

Table 6.3 – *Sensor final measures height=2cm (Lux units)*

Height = 3 cm

0°		Integration time		
		13.7ms	101ms	402ms
Gain	1x	18649	19033	19090
	16x	Sat.	Sat.	Sat.
	Auto	18649	19088	19118

-30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	16579	16907	16944
	16x	Sat.	Sat.	Sat.
	Auto	16536	16917	16959

30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	16504	16860	16864
	16x	Sat.	Sat.	Sat.
	Auto	16534	16863	16900

-45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	14384	14698	14699
	16x	Sat.	Sat.	Sat.
	Auto	14399	14678	14716

45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	12758	12998	13025
	16x	Sat.	Sat.	Sat.
	Auto	12743	13022	13050

-60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	10850	11073	11103
	16x	Sat.	Sat.	Sat.
	Auto	10880	11080	11117

60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	8124	8286	8305
	16x	Sat.	Sat.	Sat.
	Auto	8114	8269	8288

Table 6.4 – *Sensor final measures height=3cm (Lux units).*

6

Height = 4 cm

0°		Integration time		
		13.7ms	101ms	402ms
Gain	1x	11469	11698	11724
	16x	Sat.	Sat.	Sat.
	Auto	11479	11733	11762

-30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	10403	10609	10636
	16x	Sat.	Sat.	Sat.
	Auto	10403	10607	10630

30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	10072	10269	10294
	16x	Sat.	Sat.	Sat.
	Auto	10072	10284	10307

-45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	8460	8625	8647
	16x	Sat.	Sat.	Sat.
	Auto	8435	8609	8631

45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	7881	8043	8061
	16x	Sat.	Sat.	Sat.
	Auto	7911	8071	8093

-60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	6350	6480	6494
	16x	Sat.	Sat.	Sat.
	Auto	6335	6464	6478

60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	5257	5372	5388
	16x	Sat.	Sat.	Sat.
	Auto	5287	5386	5402

Table 6.5 – *Sensor final measures height=4cm (Lux units).*

Height= 5 cm

0°		Integration time		
		13.7ms	101ms	402ms
Gain	1x	7788	7950	7964
	16x	Sat.	Sat.	Sat.
	Auto	7772	7943	7959

-30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	6945	7084	7096
	16x	Sat.	Sat.	Sat.
	Auto	6945	7087	7106

30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	7016	7157	7172
	16x	Sat.	Sat.	Sat.
	Auto	6961	7096	7117

-45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	5890	6024	6039
	16x	Sat.	Sat.	Sat.
	Auto	5890	6022	6038

45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	5644	5754	5770
	16x	Sat.	Sat.	Sat.
	Auto	5628	5745	5757

-60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	4467	4557	4573
	16x	Sat.	Sat.	Sat.
	Auto	4477	4570	4585

60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	3928	3996	4005
	16x	Sat.	Sat.	Sat.
	Auto	3907	3994	4003

Table 6.6 – *Sensor final measures height=5cm (Lux units).*

Height = 6 cm

0°		Integration time		
		13.7ms	101ms	402ms
Gain	1x	6005	6132	6146
	16x	Sat.	Sat.	Sat.
	Auto	6005	6137	6150

-30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	5058	5167	5175
	16x	Sat.	Sat.	Sat.
	Auto	5043	5143	5153

30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	5395	5514	5525
	16x	Sat.	Sat.	Sat.
	Auto	5400	5501	5513

-45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	4180	4265	4274
	16x	Sat.	Sat.	Sat.
	Auto	4170	4244	4247

45		Integration time		
		13.7ms	101ms	402ms
Gain	1x	4291	4367	4371
	16x	Sat.	Sat.	Sat.
	Auto	4245	4343	4350

-60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	3243	3135	3199
	16x	Sat.	Sat.	Sat.
	Auto	3134	3197	3256

60		Integration time		
		13.7ms	101ms	402ms
Gain	1x	3130	3197	3204
	16x	Sat.	Sat.	Sat.
	Auto	3097	3159	3200

Table 6.7 – *Sensor final measures height=6cm (Lux units).*

Focusing these results on the design of the sensor tool we will determine that the furthest sensor (parallel to the LED plane) will be 6cm since it is the point where we can find less saturation and this being the most powerful LED we can play with the gain and integration time in cases of lower power.

Following this decision, and in order not to make the tool too large, we will place the side sensors at 30 degrees from the center.

Next, we will see the relationship between the measurement of the central sensor (0 degrees) and the lateral sensors (30 degrees), with the aim of determining the influence factor to obtain a single final measurement.

Relation measure 0 degrees to 30 degrees Height = 6cm				
0 to +30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	0.898418	0.899217	0.898959
	16x	Sat.		
	Auto	0.899251	0.896366	0.896423
0 to -30		Integration time		
		13.7ms	101ms	402ms
Gain	1x	0.842298	0.842629	0.842011
	16x	Sat.		
	Auto	0.8398	0.838032	0.837886

In order to be able to determine an average value for the contribution on the final measurement with the sensors at 30 degrees, we make the arithometric mean to eliminate as far as possible noise in the measurement.	
Average factor	0.869274126

Table 6.8 – *Relation factor between sensors*

We will use this factor later for data processing.

6

Chapter 7

System Design

In this chapter, topics such as computational design, physical implementation, design requirements of each subsystem, design considerations will be discussed.

The above mentioned Solidworks will be used for the computer design, this will be used for the mechanical part of the system.

On the other hand, the Altium Designer 19 program will be used for electrical design.

Figure 7.1 – *Altium Designer 19*

The complete system will be divided into the following subsystems for study:

Each one will be developed below:

7.1 Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATMega2560.

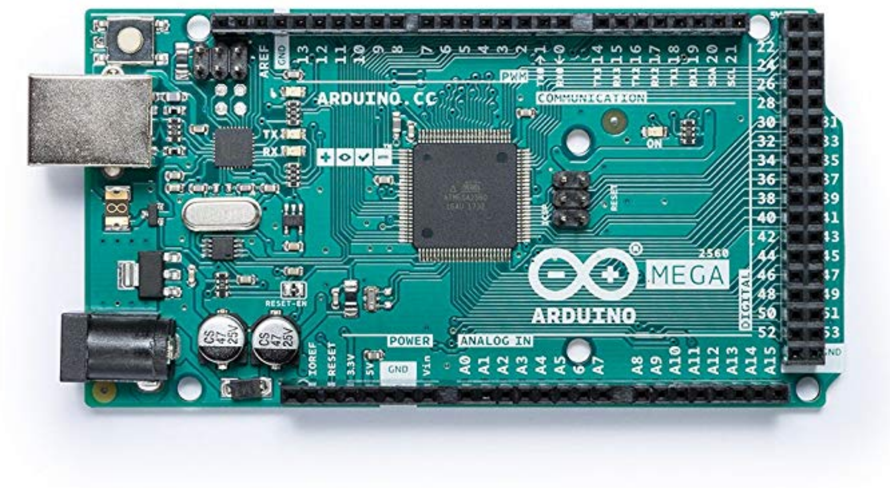

Figure 7.2 – *Arduino Mega 2560 R3*

The main features are shown below:

- Microcontroller ATMega2560.
- Operating voltage: 5 V.
- Limit input voltage up to 6-20 V.
- 54 digital I/O pins, 14 of them PWM mode.
- 15 analog pins.
- Max.I/O current 40 mA.
- DC current 3.3 V: 50 mA.
- Flash memory: 256 KB.
- SRAM: 8 KB.
- EEPROM: 4 KB.
- Clock speed: 16 Mhz.

One of the reasons why this microcontroller has been chosen due to the number of input / output pins, due to the number of devices that our final system will have.

7.2 Main PCB

This section will discuss the design and manufacturing process of the PCB that will assemble the final system.

7.2.1 Design objectives

Our final system is implemented by several subsystems for a specific function focused on meeting the requirements.

Most of the subsystems that are going to be used come in a specific packaging. This implies certain restrictions when designing and manufacturing the product.

In addition, we should try as far as possible to use commercial components to speed up the production speed focused on serial production.

Another important aspect when thinking about PCB is that it will be manufactured by an external company based on our design. This translates into the study of the different manufacturing options according to the different prices available, always thinking of reducing costs while maintaining quality.

From the previous sections, the following conclusions were drawn that our PCB design should comply with.

• The maximum dimensions that our PCB could have on each side were 10 cm. From 10 cm considerably increased manufacturing costs.

• All our components had to fit in a PCB of the previous maximum dimensions.

• We also had to adapt to the commercial cases, which means another restriction of dimensions.

• As we focus its design on the production of several units it should be designed in such a way that its assembly in the final system could be done without too much difficulty.

7.2.2 Design

Once parameters have been set to begin its design, and in parallel to the choice of other system components such as the case, it was based on an initial idea in which the components were placed in a good place but the design of the pcb exceeded the dimensions we had established as " limits ´´ for its manufacture.

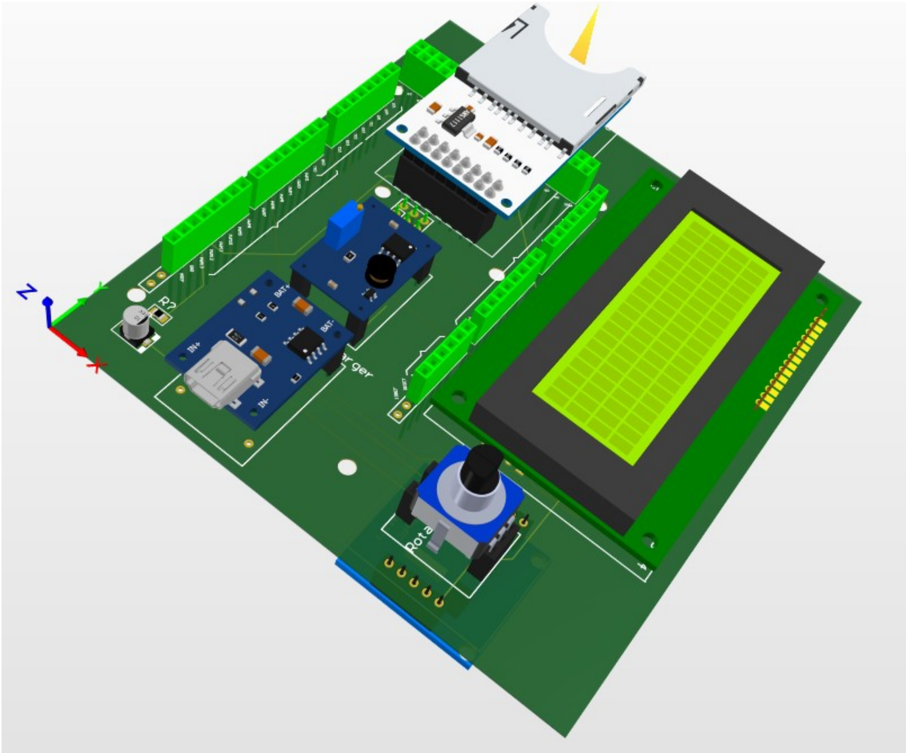

Figure 7.3 – *Top view of the PCB v1*

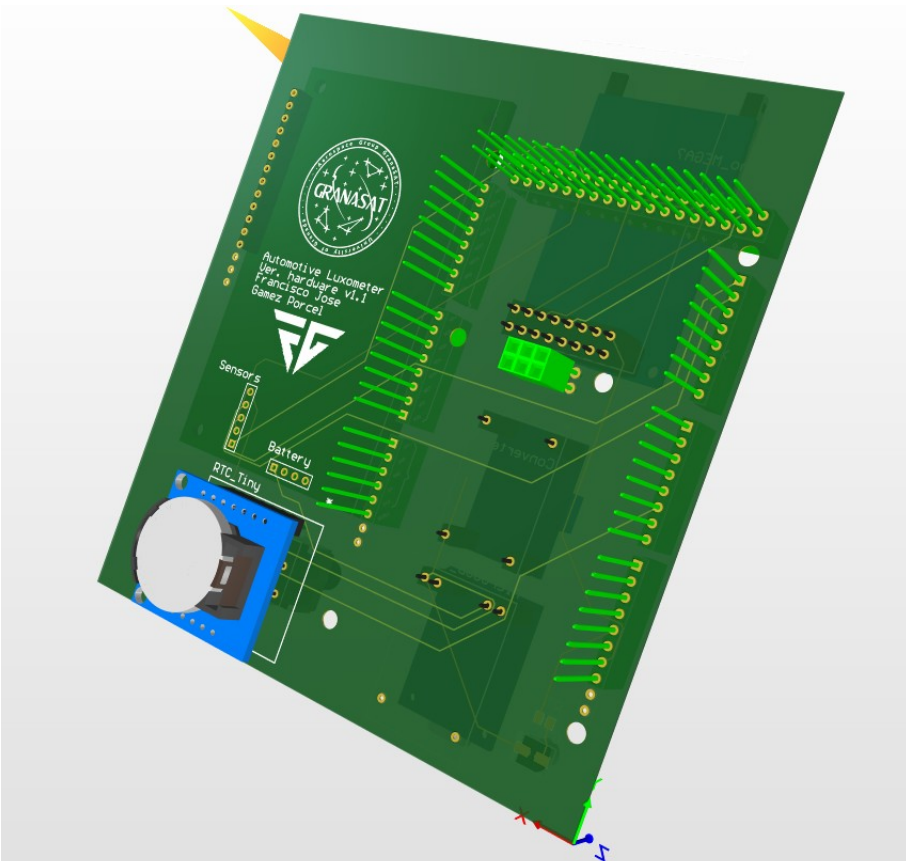

Figure 7.4 – *Bottom view of the PCB v1*

After reviewing the PCB, commenting on the results and applying the process concurrently the following requirements were added:

⊕ We had to size the tracks with different widths due to the power for which they are designed.

⊕ We add four holes to fix the PCB to the final case.

⊕ Disconnecting capacitors of both low and high frequency were added to avoid possible noise and interference in our signals.

Next, the design of the PCB with the established dimensions is shown:

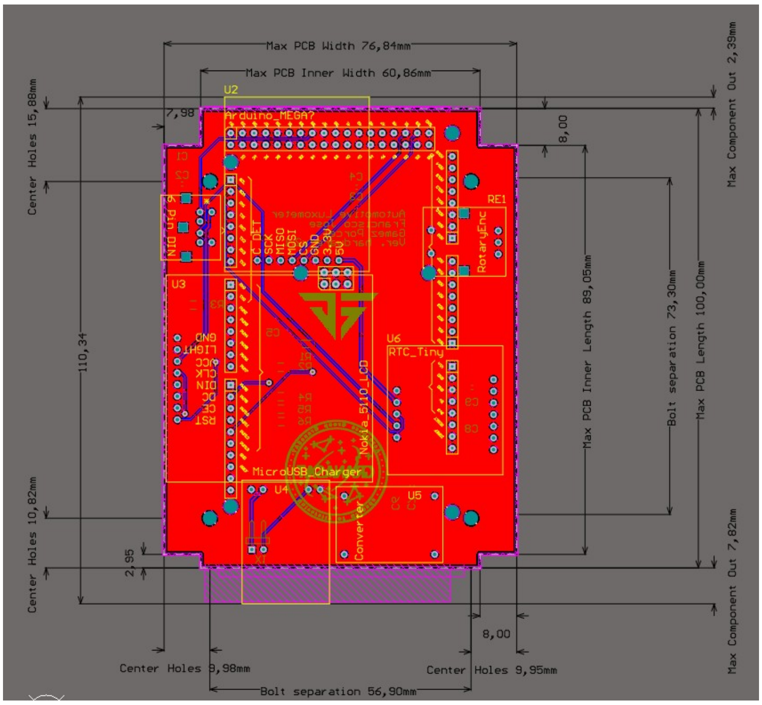

Figure 7.5 – *Top view of the PCB v2 board*

7

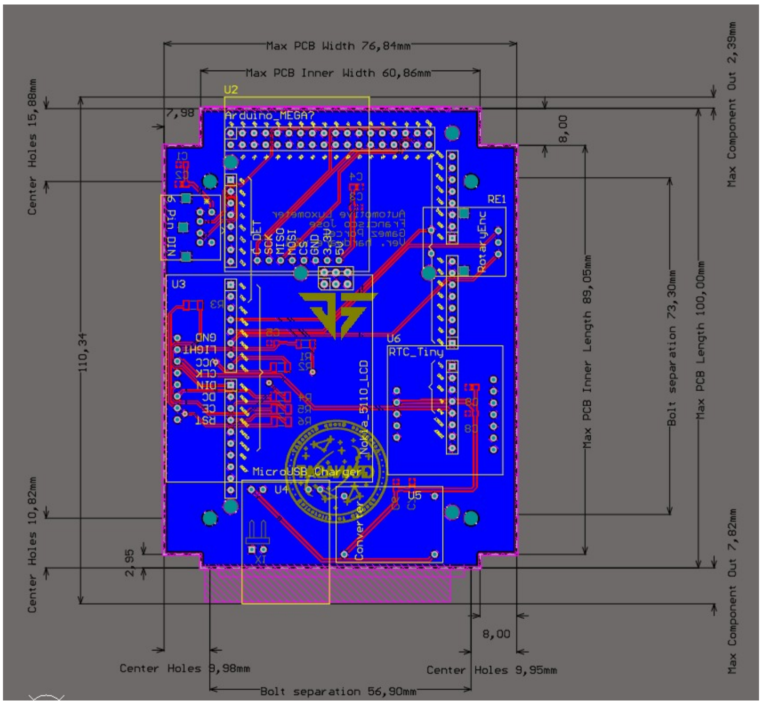

Figure 7.6 – *Bottom view of the PCB v2 board*

The 3D models of it:

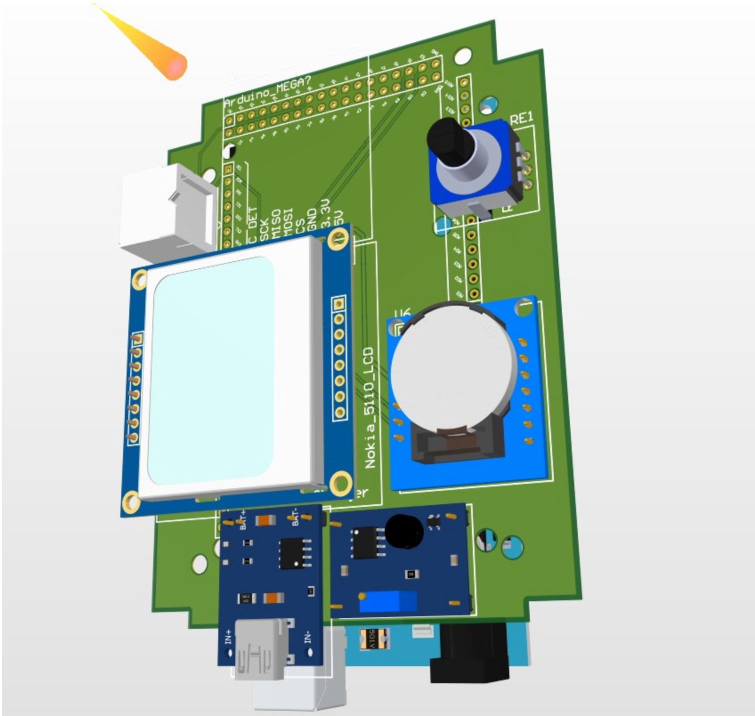

Figure 7.7 – *Top view of the PCB v2*

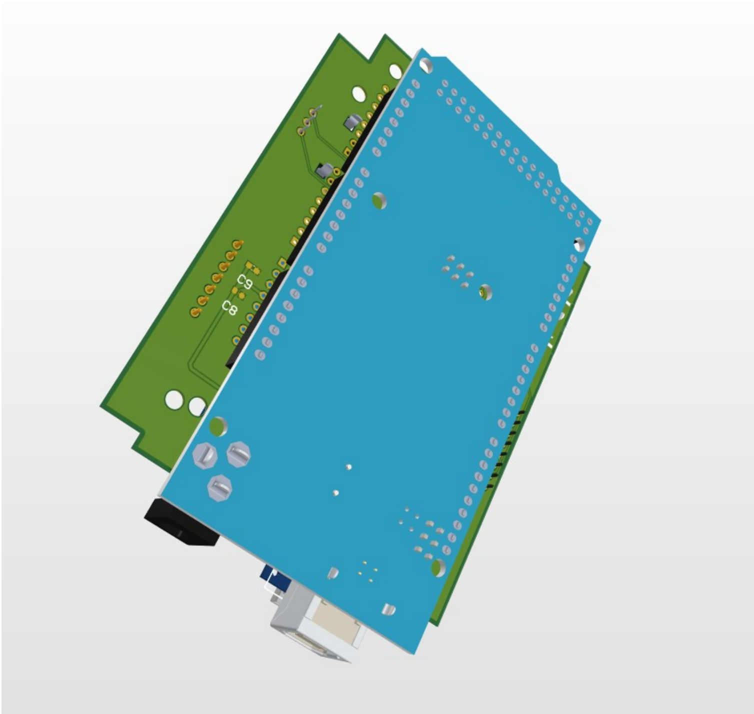

Figure 7.8 – *Bottom view of the PCB v2 with Arduino board*

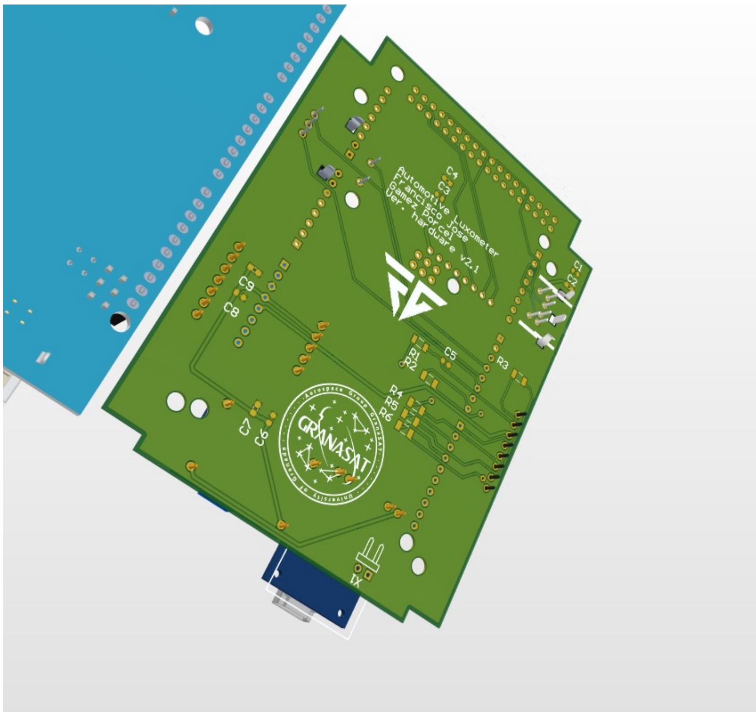

Figure 7.9 – *Bottom view of the PCB v2 without Arduino board*

As we can see, some elements were also changed since this process, as we have said before, was carried out in parallel to the study and design of other components to in any case induce improvements in our system.

7.3 Power Modules

In this chapter, everything related to the power supply to our device will be discussed, as well as the adequacy of it for its correct operation.

The first of all was to think about how we were going to power our device. We would do this through a battery which we can recharge with the same type B USB socket that we use to program the device.

The type of battery that we would use is a LiPo 3.7 V. As we have seen before our microcontroller needs a 5 V supply voltage. To supply the appropriate voltage we will use a boost converter.

7.3.1 Power conversion

To power our device properly we use the boost converter SX1308, a low cost converter that meets our specifications and with adjustable output. Below we see its main features:

Input voltage: 2-24 V.

Output voltage: 2-28 V.

Max output current: 2 A.

Switching frequency: 1.2 Mhz.

Iddle current: 1.9 mA.

The module and the schematic are shown below:

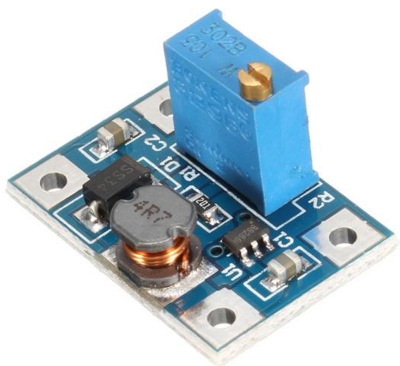

Figure 7.10 – *SX1308 Module*

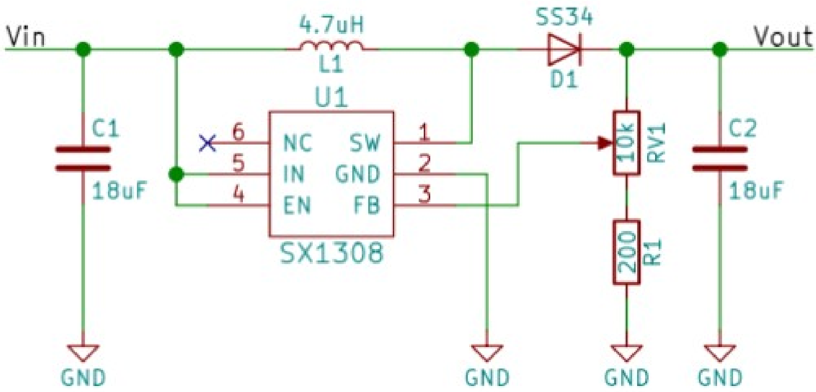

Figure 7.11 – *SX1308 Schematic*

An important aspect to consider for the subsequent calculation of the power budget is it's efficiency. From the device data sheet we get:

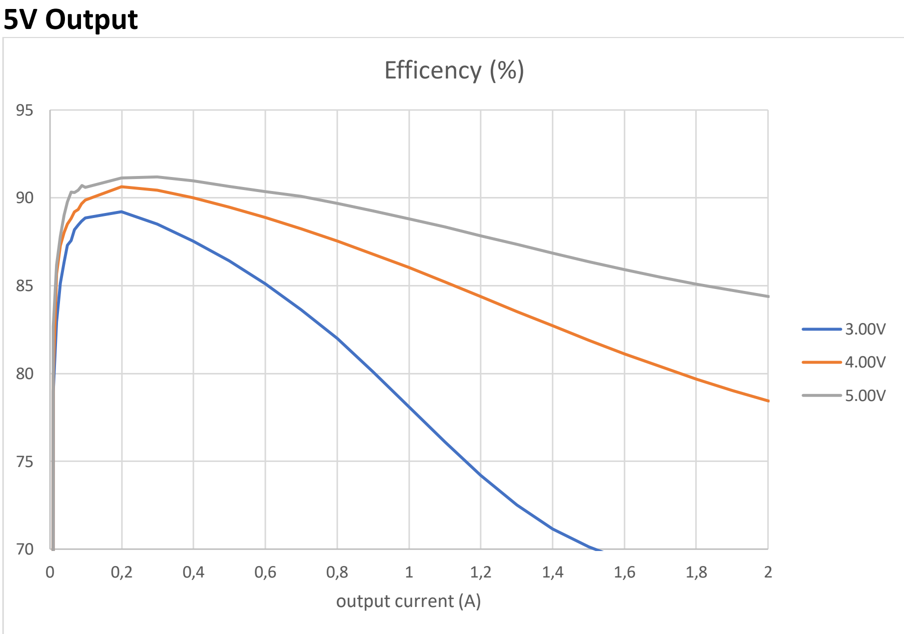

Figure 7.12 – *SX1308 5V output efficiency*

7.3.2 Recharging the battery

The following module will be used to charge our battery:

Figure 7.13 – *TP4056 Module*

This module uses the TP4056 Li-Ion charge controller IC and a separate protection IC. There are other types of modules on the market that use the TP4056 but lack any protection circuits or ICs to provide the necessary protection needed with lithium batteries. This module uses both the TP4056 and the DW01A Li-Ion battery protection IC, which together in combination provide the following protection features:

- Manage the constant current to constant voltage charging of a connected lithium battery.
- Over-discharge protection.
- Overcharge protection.
- Overcurrent and short-circuit protection.
- Soft-start protection limits inrush current.
- Trickle charge (battery reconditioning) - if the voltage level of the connected battery is less than 2.9V, the module will use a trickle charge current of 130mA until the battery voltage reaches 2.9V, at which point the charge current will be linearly increased to the configured charge current.

Also it Can be powered, for charging, from a micro USB cable or the + and - connection.We we use this conections to directly connect it to 5V pin of the USB B type of the Arduino.

7.3.3 Power budget

In order to size a battery according to an adequate usage time, we have generated the following power budget based on all the devices that have been used.

Power Budget				
Device	Power Consumption 3.3 V		Power Consumption 5 V	
	Typical (mA)	Max (mA)	Typical (mA)	Max (mA)
Arduino Mega 2560			30	54
TSL2561 5x	1.2	3		
MicroSD/SD			0.2	150
RTC Mod.			1.5	1.5
LCD 5110 Nokia	6	8		
Total	7.2	11	31.7	205.5
3.3v Reg. AMS1117* E.F	9	13.75		
Total 5V			40.7	219.25
SX1308* (E.F)	0.9	0.91		
Total Device Consumption	8.00	12.09	45.22	240.93
*AMS1117 this current has been calculated considering the efficiency of the 5v to 3.3v regulator in order to calculate the total current consumption for 5v potential.				
*SX1308 the total SX1308 device consumption has been calculated considering the total efficiency of the device, that depends on the output voltage and the output current. The efficiency is shown in the Tab.1 Pag.2 SX1308 Datasheet				

Figure 7.14 – *Power budget*

Once we generate the budget it is verified that it is really that consumption that our device has, for this we use the following device:

Figure 7.15 – *Charger Doctor device*

This device informs about the voltage and current consumption of our projects. We will use it to verify that the estimated consumption through the power budget resembles the real one.

Figure 7.16 – *Device current consumption*

In the previous image we see the consumption of our system with 5 sensors connected. As we can see, it consumes 100mA, an intermediate consumption between typical and maximum estimated values.

7.3.4 Battery

Once we know the consumption of our device we are able to size a battery to power it.In our case, due to the size available in the case, the following battery has been sized.

Figure 7.17 – *Battery model*

The battery has the following characteristics:

- Rated voltage: 3.7V.
- Battery charge: 1800mAh.
- Power: 6.6Wh.

In relation to the previous data, the battery life of our device is estimated.

$$Battery\ duration = \frac{Battery\ charge}{Device\ consumption} \tag{7.3.1}$$

$$Battery\ duration = \frac{1800mAh}{100mA} = 18h \quad (7.3.2)$$

7.4 GUI modules

In this section we will talk about the interfaces with which the user will interact directly, these are: the LCD screen and the rotary button.

7.4.1 Interfacing 5110 LCD

In this project we will use the LCD screen of the Nokia 5110 that is sold as a complete module as shown in the image.

Figure 7.18 – *Nokia LCD 5110*

It´s a 48x84 pixels matrix LCD.

This screen was chosen from among all possible market options for its price, sufficiency to display the necessary data, adjustable contrast and adjustable backlight.

As main points within the adaptation of this to our project we will differentiate the following sections: the adjustment of the backlight using PWM, the adjustment of the contrast and a brief description of the menus that we want to appear in it.

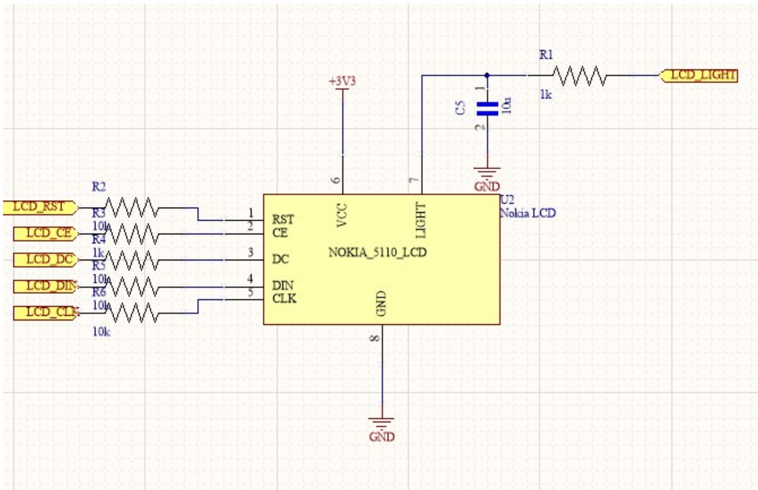

Figure 7.19 – *LCD5110 wiring diagram*

As we can see in the image 7.19, resistors have been added to protect the screen against overvoltages, since it should not be powered at more than 3.3V.

7.4.1.1 PWM control of backlight

One of the main features of our screen that we can take advantage of is the backlight control.

This control is done by applying a continuous voltage on pin V0. The range of accepted voltages is 0 to 3.3 V. As we know our arduino Mega provides a voltage of 5V on its digital pins. In order to pass from this voltage to the 0-3.3V range, one of the main features of the Arduino will be used as it is capable of generating PWM signals. From this PWM signal with a low pass filtering we will be able to vary the voltage between the desired range obtaining a continuous voltage value.

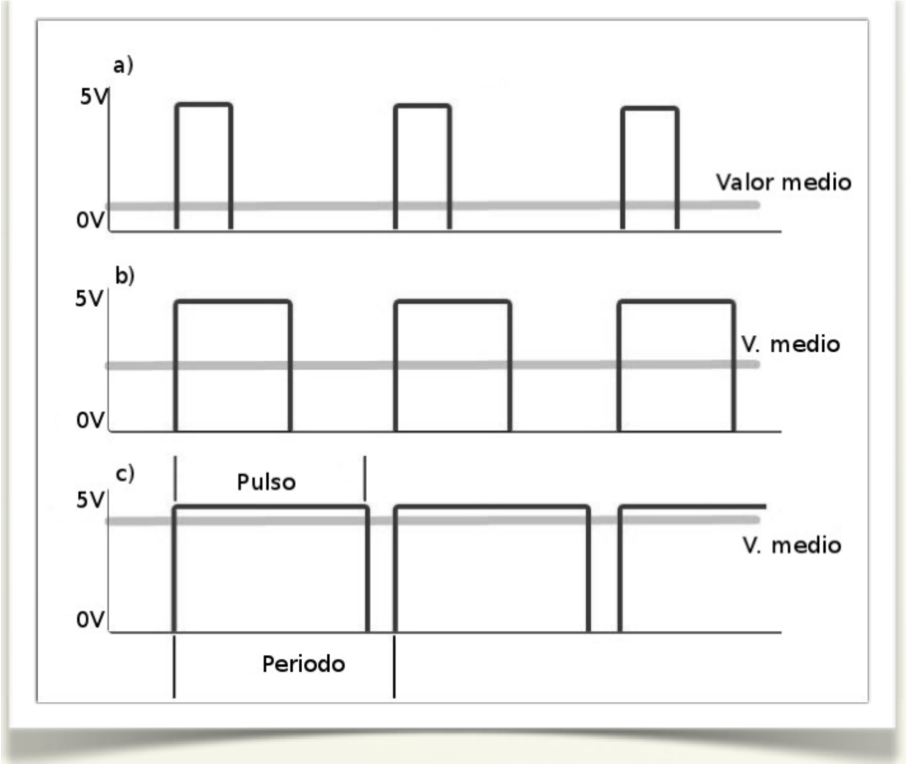

Figure 7.20 – *0 to 5V PWM signal*

In the previous image we can see how a PWM signal works.Pulse-Width-Modulation is a method that can reduce the average power delivered to a load by an electrical signal through discrete parts. This is done by varying with a certain frequency the value of the voltage causing the average output voltage to be among the limit values between which the signal varies.

This generates a noise that can cause distortion in the output signal that, as we have said, we want it to be costly (continuous voltage). This is due to the very principle we use to create the signal, through an alternal signal. To pass from this alternating signal to a continuous signal we will use a low pass filter, which will let the low frequencies of the signal pass by as the name implies. For this project we have used the following low pass filtering.

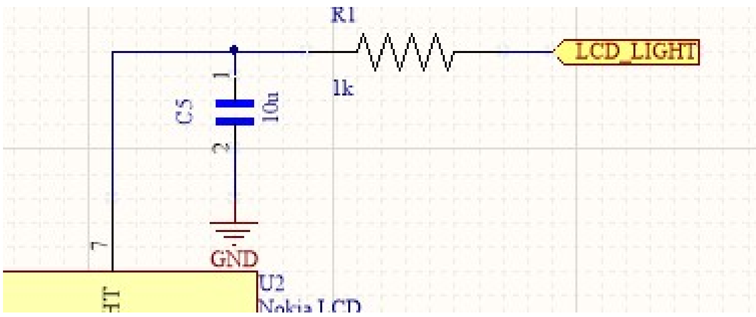

Figure 7.21 – *Low pass filter for backlight adjustment*

With this system we can vary the values of the (continuous) voltage that we apply to the backlight pin.

By varying with PWM values that we can see in the programming chapter we obtain the following results:

Figure 7.22 – *LCD backlight adjustment*

To provide ease of use to the customer and taking into account the conditions of use, it was decided after using the device to keep the backlight fixed at its maximum value.

7.4.1.2 Contrast adjustment

This function allows us to vary the contrast of the LCD screen between certain values that we consider to be adequate when programming the device.

We can set the contrast of the display using setContrast(value) function with value can be anywhere between 0-100.

Of all these values,we find the best results in the range of 55 to 75,which in this case we have divided as before into 5 different types of contrast settings.

Next we see the results obtained on the control of the contrast of our screen.

Figure 7.23 – *LCD contrast adjustment*

7.4.1.3 Menus

To navigate between the different modes and make the most of the possibilities of our device we must design a menu system that is intuitive and easy to navigate to facilitate, as far as possible, the use of the device by the user.

For this, the main menu will have the different functions:

⇒ Measure mode: to use the main function of the device to sample with sensors.

⇒ System setup: to adjust the main parameters related to the system.

⇒ Sensor setup: to adjust the gain values and integration time.

⇒ Save: in this mode we will save the data sampled by the sensors along with the date and setting parameters.

⇒ Last saved: in this mode we can access the latest saved data.

7.4.2 Rotary encoder

One of the main elements with which the user will interact is the rotary button.

Initially it was thought to use a joystick but in the study of the different possibilities the rotary button presented us with considerable improvements such as: greater ease of use, use of interruptions at the time of programming since it works with digital values, greater number of possibilities of use with the same device.

To implement this system a rotary encoder was used. It is an electro-mechanical device that converts the angular position or motion of a shaft or axle to analog or digital output signals.

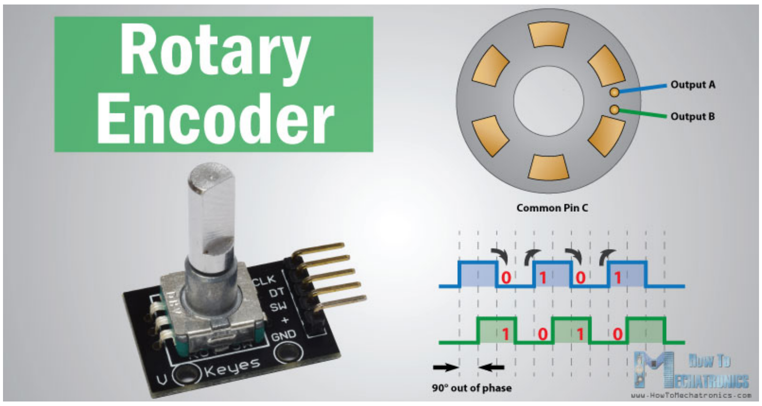

Figure 7.24 – *Working principle of the rotary encoder*

As we can see in the image, this device works by alternating the 90 degree offset between two signals as we turn to one side or the other. For the case in which we press the button, it sends a digital signal as well.

In our case we have used the following commercial device:

To use it comfortably, a button must be designed on which the user will interact. The design and assembly of it will be seen in later chapters.

7

Figure 7.25 – *Comercial rotary encoder*

This device comes with 5 terminals whose wiring will be detailed below and also comes with two anchors by which it will provide us with a greater grip on the PCB.

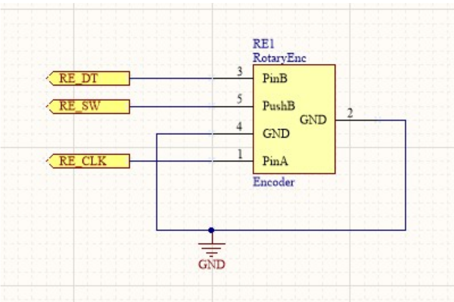

Figure 7.26 – *Rotary encoder schematic*

This device must have connected pull-up resistors, in the schematic 7.26 they have not been introduced because we have introduced them via software as we will see in the chapter referring to programming.

7.5 Memory

As we have seen in previous chapters, initially in the first version of the PCB an SD card module was introduced to store the measurement data. As we can find better features on microSD cards, the initial module has been changed to one capable of supporting both card formats.

This module allows us to use memory cards with a maximum of 2GB and can be powered with both 5V and 3.3V. It also has a very useful function for our case, focused on the use of the client that is the card detector.

Figure 7.27 – *MicroSD/SD High speed module*

Below is shown in the schematic (figure 7.28) in which we also observe the decoupling capacitors.

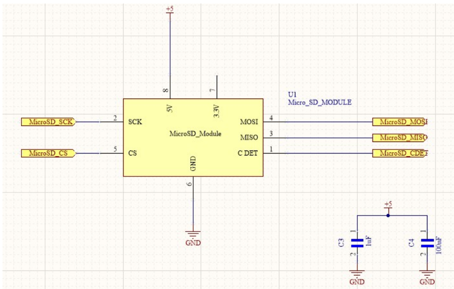

Figure 7.28 – *MicroSD/SD High speed module schematic*

7.6 Real time clock

When we work with large amounts of data, it is very useful to be able to register them associated with a date and time in order to be able to easily locate them for processing. Our microcontroller once you disconnect it from the power supply is not able to keep a certain date and time saved.

For this purpose, an RTC-DS1307 module will be used. This uses a LIR2032 battery. As a communication interface it uses the I2C bus and is powered at 5V. This device is capable of maintaining both the date and the time in case of disconnection of our system, since it has its own power supply.

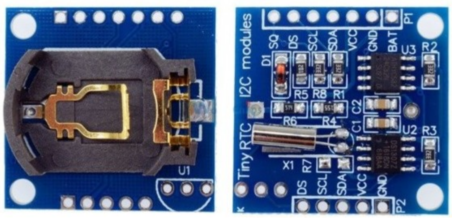

Figure 7.29 – *Real time clock module*

And his schematic:

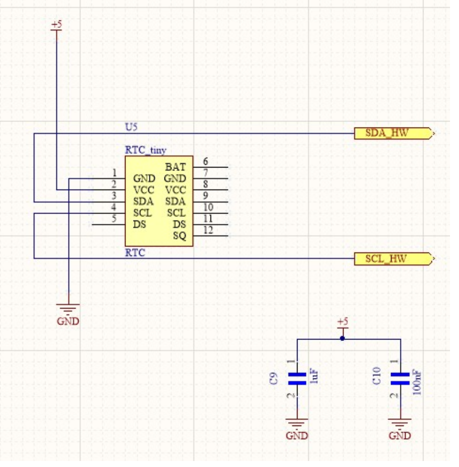

Figure 7.30 – *RTC Schematic*

7.7 Buzzer

During the development phase, it was thought to add a buzzer 7.31 that emitted a small sound every time the program read any reading of the rotary button.

Figure 7.31 – *12mm buzzer*

7.8 Mechanical design

Once we have all the electronic components chosen and we know what size they can occupy approximately, in parallel, we look for a protection box for our product that is commercial since one of the characteristics of our product is that it is easy to assemble.

7.8.1 Using a commercial case

Among the different possibilities offered by the market, guidelines were set in terms of size, use, ergonomics, robustness, etc.

After a search between the different options and taking into account the quality / price ratio it was thought that the following case was the most appropriate for our product.

Below we see an image of the manufacturer's datasheet which were very useful for the sizing of the PCB.

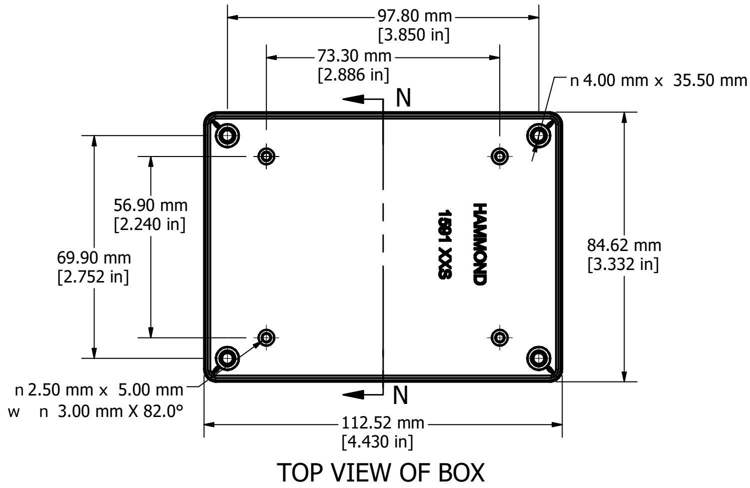

Figure 7.32 – *Top view of the case*

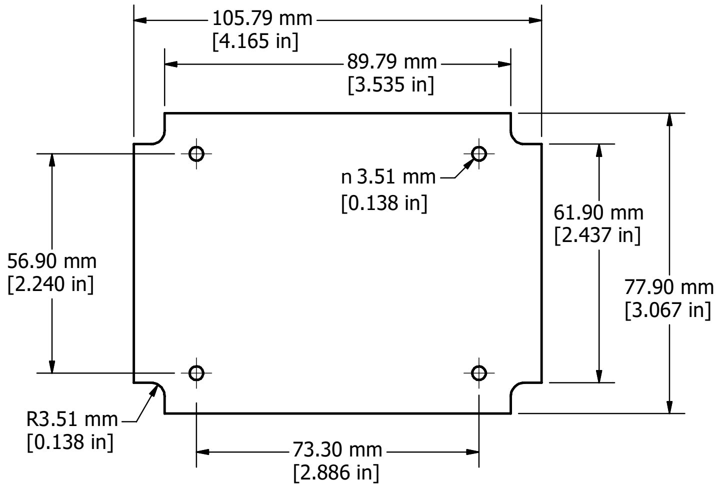

Figure 7.33 – *Maximum PCB size*

As we can see, this case has some internal holes in which the pcb can be fastened by screws.

On the other hand we see the maximum size that the pcb can have, including the holes for its fastening screws. Due to the maximum manufacturing dimensions that we established in previous chapters, our PCB will be somewhat shorter to not exceed 10cm as we can see in the image 7.7 PCB top view.

We can find more information about the dimensions of this case in the appendix:??

7.8.2 Adapting the case to our product

In order to use this case for our product it needs to be adapted by making various changes since this case is prepared for standard prototypes. Next, all the changes that have been made in the box from its initial state to its final state will be presented describing the process and the components that have been added.

Figure 7.34 – *Original case*

In the previous photo we can see how the box originally came in which we can also see the holes for the fastening screws of the PCB. Because our product has a screen, connectors, a rotary button etc. we need to make the necessary holes for these components.To do this, a dremel has been used, continuing with a sandpaper to perfect the finishes. Below we see a photo 7.35 of this partial result.

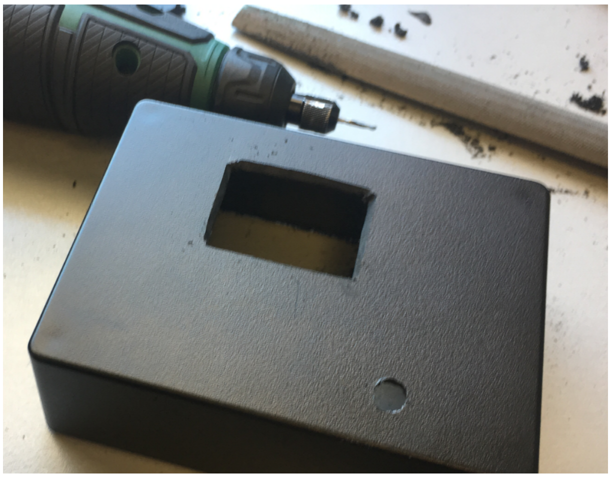

Figure 7.35 – *Modified case with screen and the rotary button holes*

7.8.2.1 Screen protector

Due to the working conditions of our device, it is necessary to add a screen protector to prevent most of the dust and protect the LCD against possible shocks etc.

For this purpose, 3mm methacrylate has been used which, through the SolidWorks program, was made the sketch of the necessary cuts to adapt it to our case and subsequently it was passed to a laser cutting program to be used in a laser cutter 7.36.

Figure 7.36 – *Laser cutter machine*

The result after the cut we see in the following image:

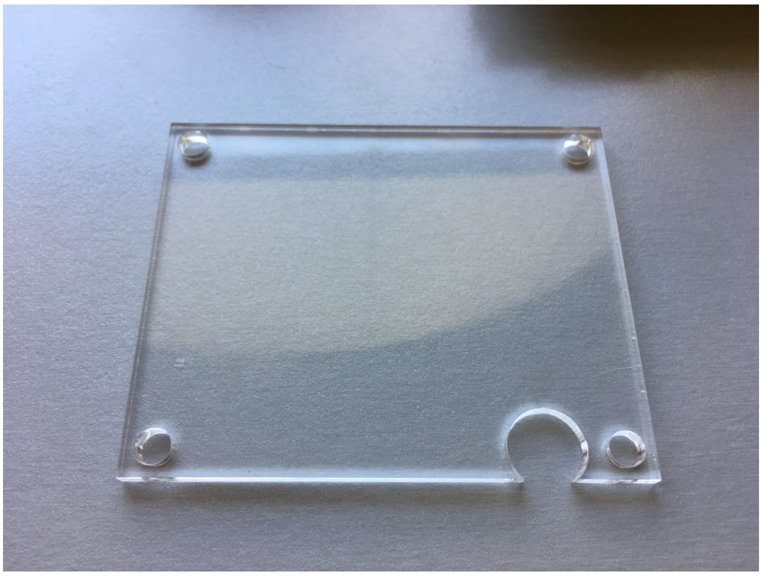

Figure 7.37 – *Methacrylate Screen Protector*

In it we observe the holes that have been made so that it is at the same height as the holes to put the screws of the pcb and another large hole to pass the rotary button.

7.8.2.2 Rotary button

As we said before, a rotary encoder will be used to control our device but it cannot be presented as such to the user because it is not ergonomic enough. For this purpose, the following button that was subsequently printed in 3D has been designed by SolidWorks.

Figure 7.38 – *Rendered button design*

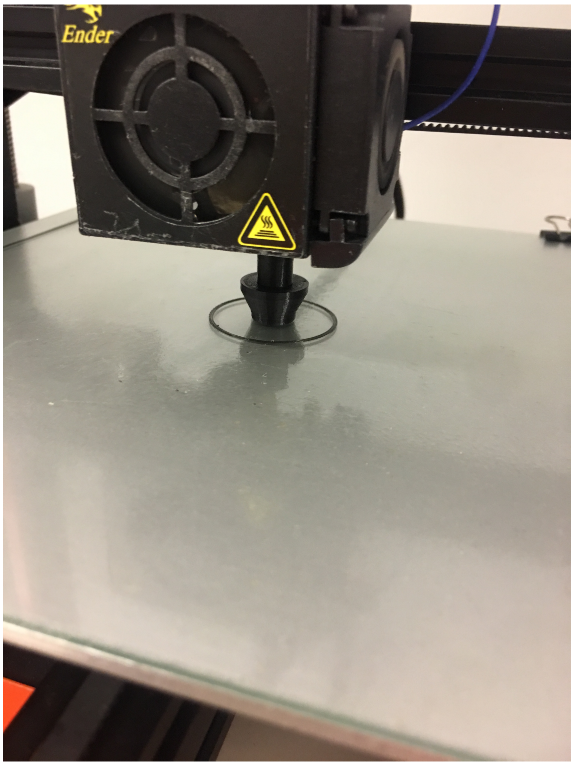

Figure 7.39 – *Button printing process*

Figure 7.40 – *Final appearance of the button*

As we can see, the rotary pin was made in the same way as the button to fit perfectly.

7.9 Software design

Once we have the hardware designed we have to design the software that will control our device.

First of all we have to think about how the client will use it, what their preferences are and from this, design a system that is accessible and intuitive.

To do this, we design a state machine in which, depending on the control over the rotary button, we will navigate through some functions or others.

Below is a list of the following project requirements as far as software is concerned:

- When starting it, the system must start in measurement mode since it is the end of said device and rapid use of the device is required.
- We must be able to adjust the parameters of the sensors.
- We must be able to adjust the system parameters both those of the screen and those of the date and time system.
- We also have to have a way to save the data for further study.
- We will add a mode that shows the latest saved data.
- The system must give a warning in case of not having a memory card when entering any of the modes that require it.
- The system must notify in case of failure of any sensor.

7.9.1 State machine

Once we have defined our main requirements we move on to the phase of the state machine study, that is, how our system reacts to the different interactions with the rotary button.

Next we see the main state machine of the program that allows us to recognize the program modes according to the different menus.

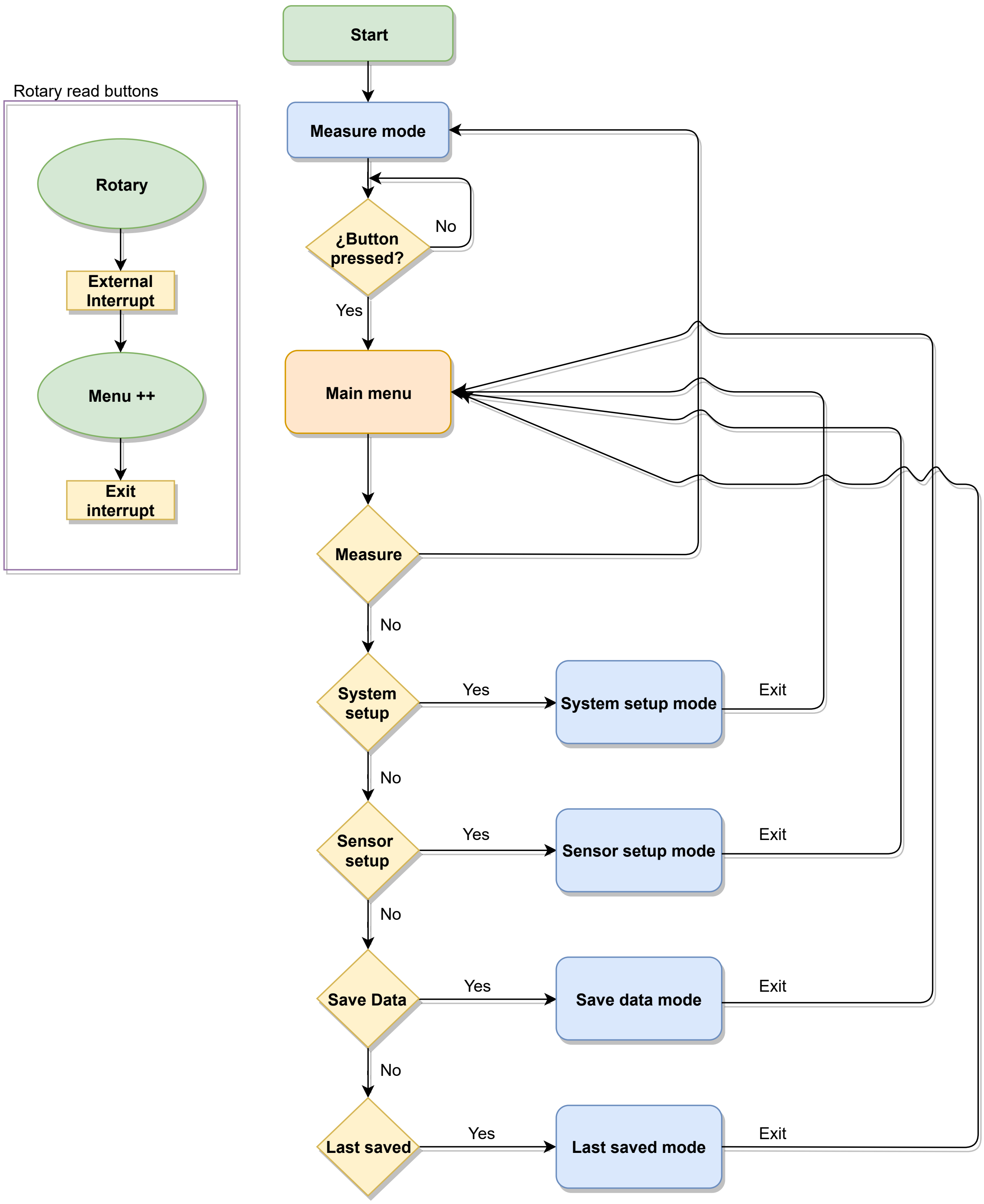

Figure 7.41 – *Main menu state machine*

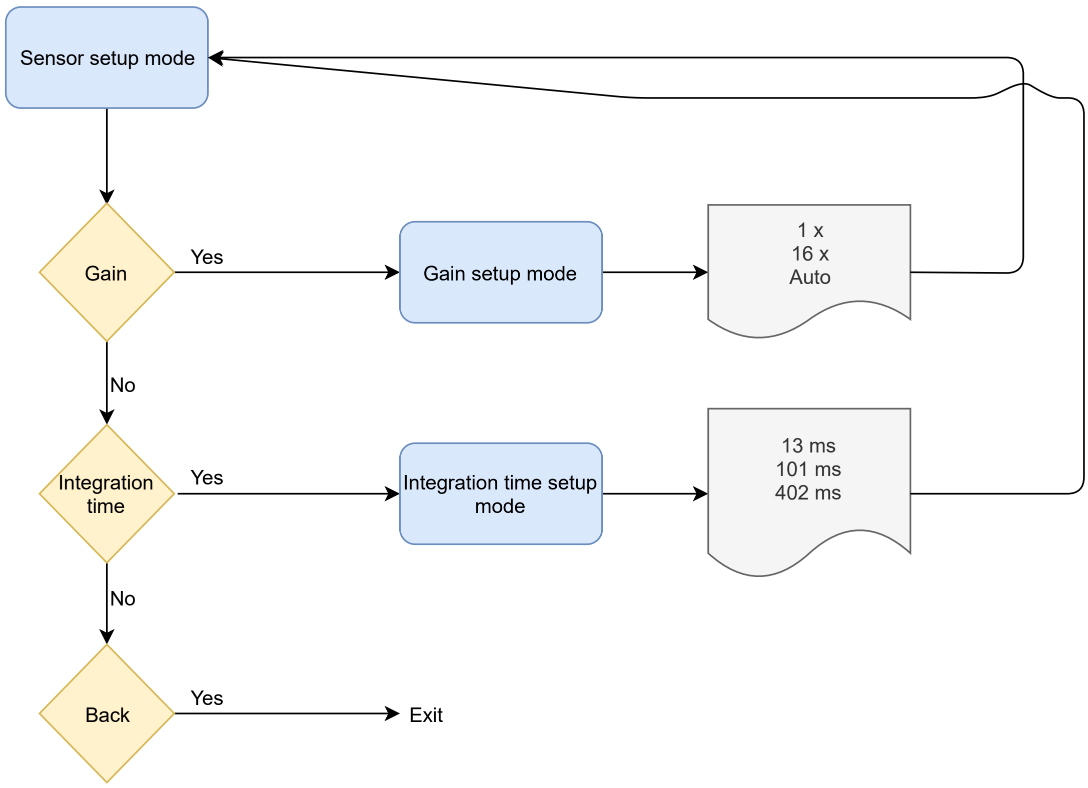

Figure 7.42 – *Sensor setup menu state machine*

7

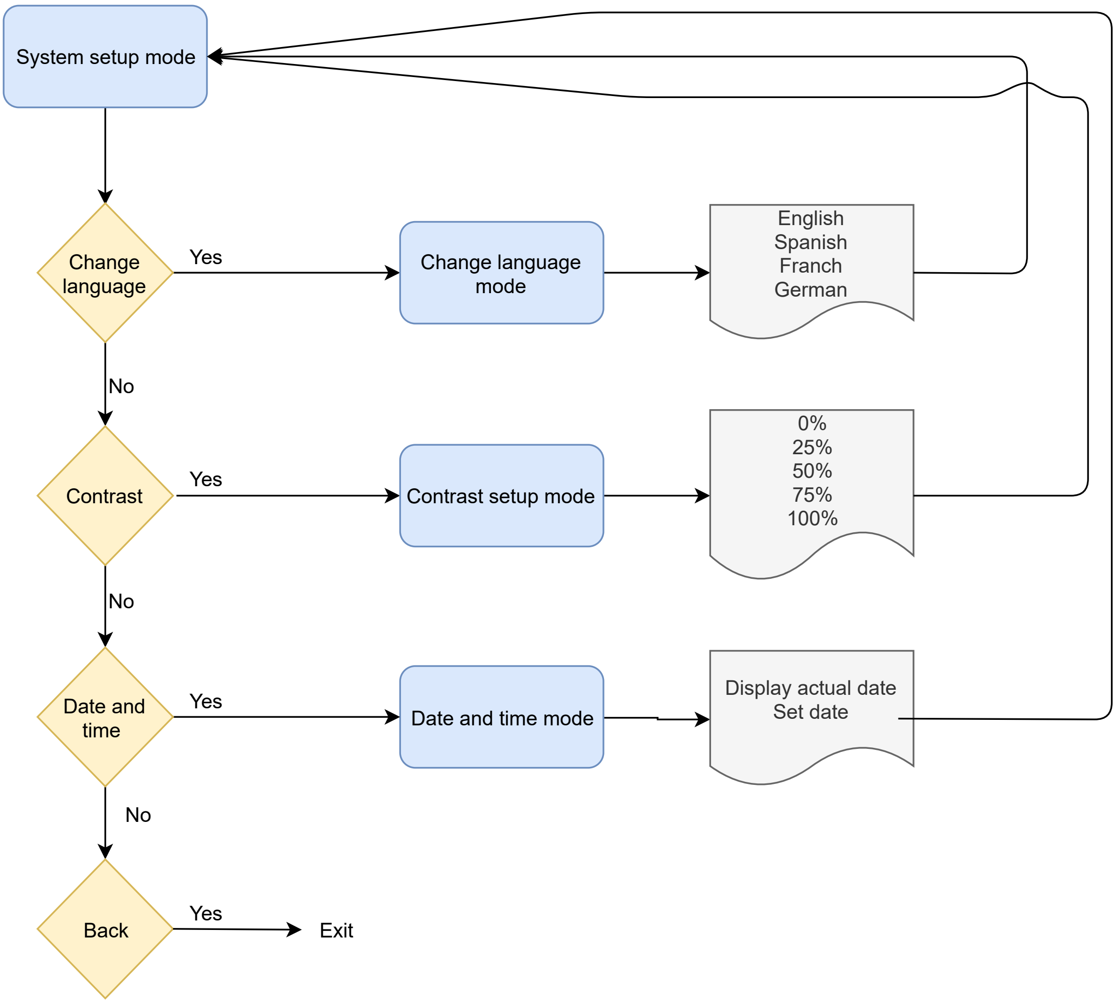

Figure 7.43 – *System setup menu state machine*

In the figure 7.41 we can see the main state machine with the different options that we can find in the main menu, then in the figures 7.42 and 7.43, an expansion of these functions with its internal submenus is shown.

Next we will describe each of the main functions.

7.9.2 Main functions

Thinking about the use that the customer will give to the device, the following functions have been included (Denoted in blue in the diagrams of the state machine)

Measure mode: in this mode the measurement of the five sensors in lux units is shown and also a processing is performed to show a single measurement in lumens units.

Save mode: this function shows the parameters of the sensors with which we are working as well as the lumens value of the measurement. There is the option to save the reading that also adds in the file saved the reading in lux of each sensor.

Last saved: shows the last saved data.

Sensor setup: allows us to change the operating settings of the sensors 7.42.

System setup: allows us to change the values shown in the figure 7.43.

7.9.3 EEPROM

EEPROM memory, *Electrically Erasable Programmable Read-Only Memory (programmable and electrically erasable ROM)*. It is a type of ROM that can be programmed, erased and reprogrammed electrically.

In our case as we have commented in the section 7.1.Our microcontroller has a 4 KB EEPROM.

This will be very useful to us since we will store the main data referring to the device setting in the EEPROM, so that they are preconfigured once we restart the system. It is **very important** to keep in mind that the EEPROM has the limited writings therefore in our program we must verify that if the data that we are going to save is the same that the previous one does not write the same again.

7.10 Sensor tool design

7

Starting from the results obtained in the chapter 6.6, we will design the tool that will house the sensors inside. In summary, the following design considerations will be taken:

- It will have 5 sensors, 1 central and 4 on the sides, with 90 degrees between them.
- The central sensor must be 6cm from the LED. (Point where maximum illuminance is obtained)
- The lateral sensors will be 30 degrees inclined with respect to the central one.

As we have said in previous chapters, **this design is governed by LEDs with a radiation pattern of the Lambertian emitters type.**

In SolidWoks we start designing the part that will support the sensors. Due to the printing limitations we have divided this tool into three parts that will be printed separately.

Below we see an image 7.44 of the program during its design. In it we can see the definition of the angles and the height with respect to the LED (center point of the circle) in mm.The piece was designed so that the sensor inside the TSL2561 module stayed right in the center at the desired angles.

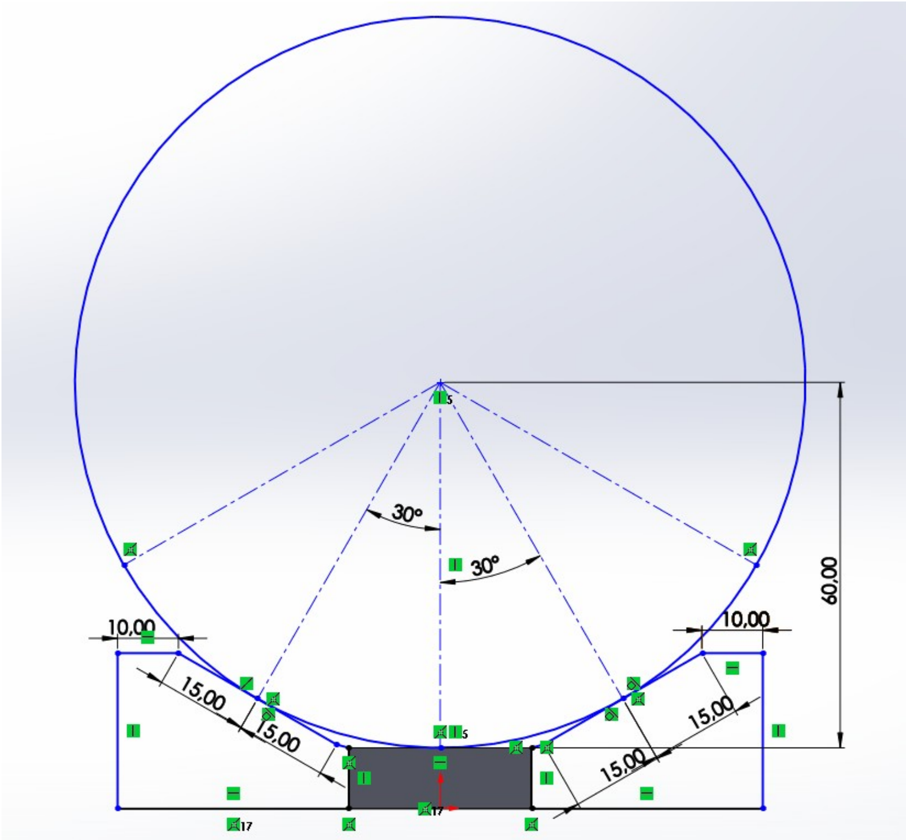

Figure 7.44 – *Sensor tool design SolidWorks*

With this same program we design the different parts that make up the tool.

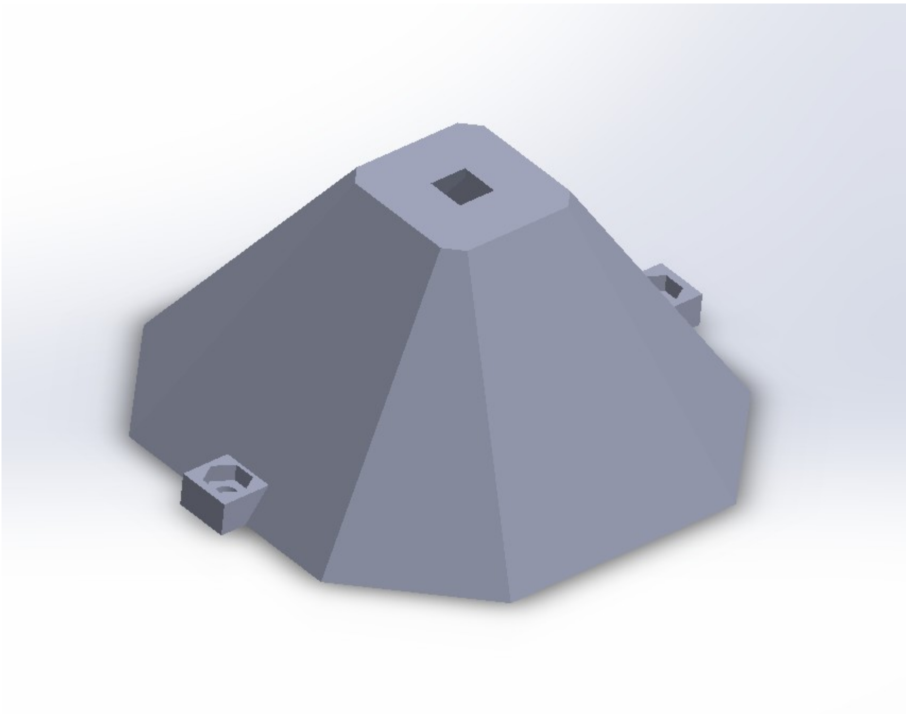

Figure 7.45 – *Sensor bell SolidWorks*

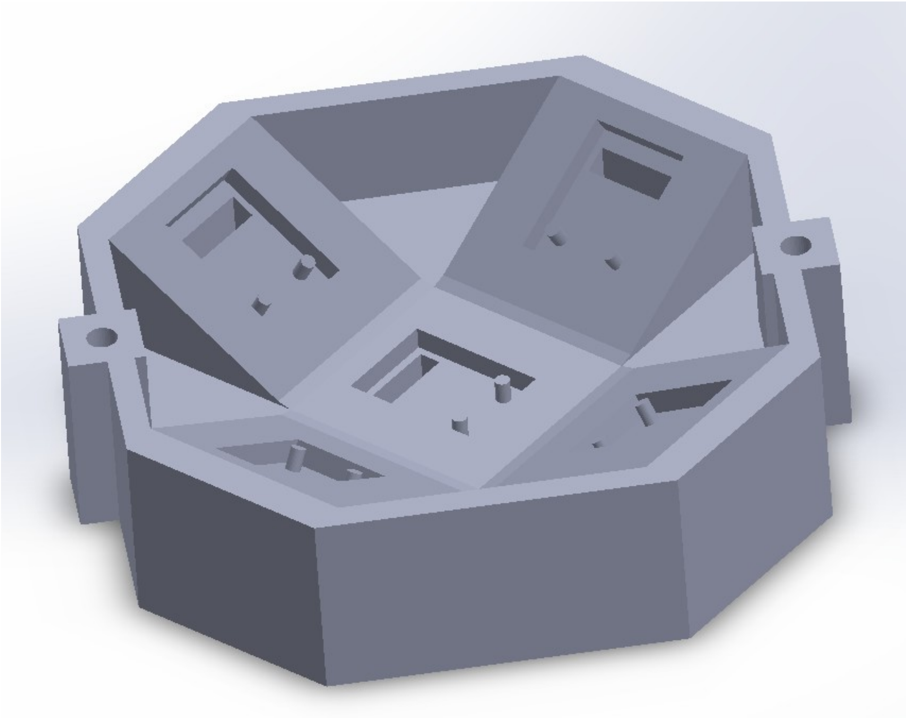

Figure 7.46 – *Sensor support SolidWorks*

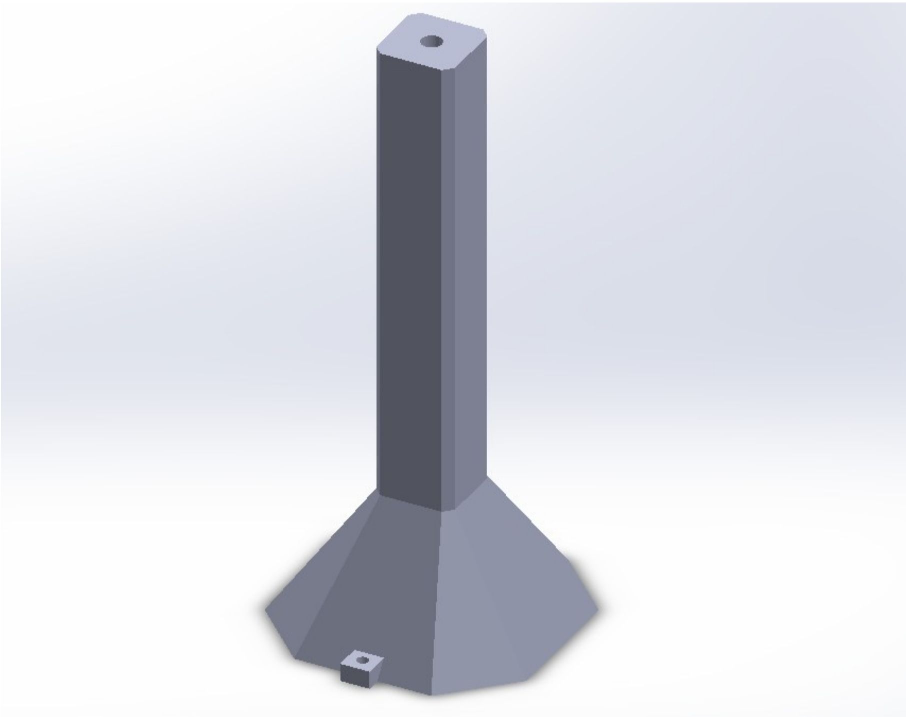

Figure 7.47 – *Tool support SolidWorks*

7.11 Using the same port for charging and programming

In order to reduce wiring and improve the consumer experience, it was thought to use the same USB type B port, which is used to program the Arduino, for system charging, that is, we would not use the microUSB port of the charger module.

Initially it was thought to use the 5V that the type B port provides when connecting it but this was a problem.

When the Arduino was powered externally at 5V, the port where the USB Type B connector is connected was also set to this potential, this means that the charger module also turned on without actually being connected to charge.

To solve this process we look at the schematic of the Arduino Mega B and look for the system by which it is powered. Once located, to solve this problem, a Schottky diode was placed between the drain and the source of the Mosfet transistor T1 that we see in the following image (figure 7.48). With this we get that this port is not put to 5V to power externally the arduino and with it we solve this problem.

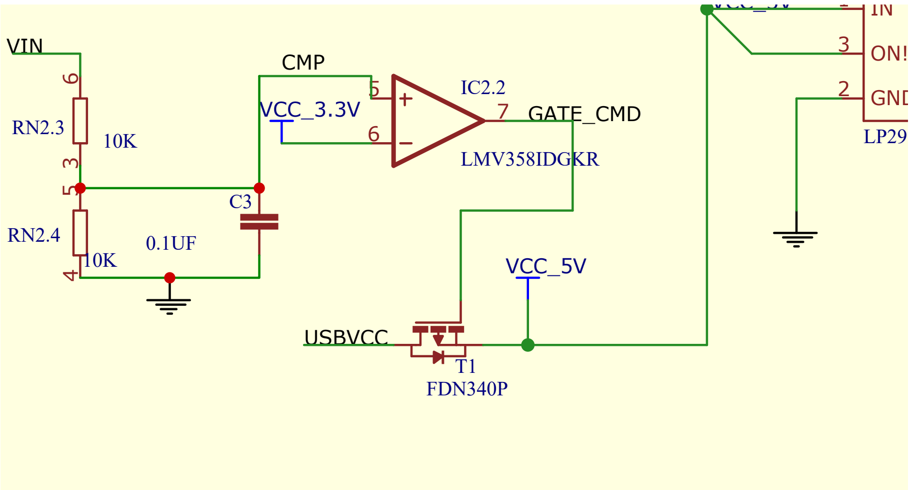

Figure 7.48 – *Input USB system Arduino Mega Sch*

In the charger module we connect the 5v input of the USB type B port to the IN + and IN- terminals of the figure7.13.

Chapter 8

System manufacturing

In this chapter we will assemble the complete main system and we will manufacture the sensor tool based on the conclusions obtained in the section 6.6 and designed on the section 7.10.

8.1 PCB Manufacturing

Once we have our PCB designed, after fully performing we go looking for a method to manufacture it.

Among the options available we had several manufacturers online and the option to manufacture it in the GRANASAT laboratory as shown in the figure 8.1. The latter was done by isolating the tracks by a CNC machine.

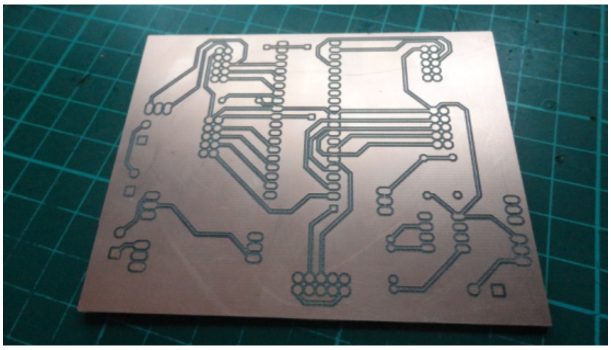

Figure 8.1 – *PCB done with CNC machine*

Shuffling the different options and balancing the costs it was decided to send it to an external manufacturer for its manufacture.

J@LC JLCPCB

Figure 8.2 – *JLCPCB*

Next we see the result after manufacturing.

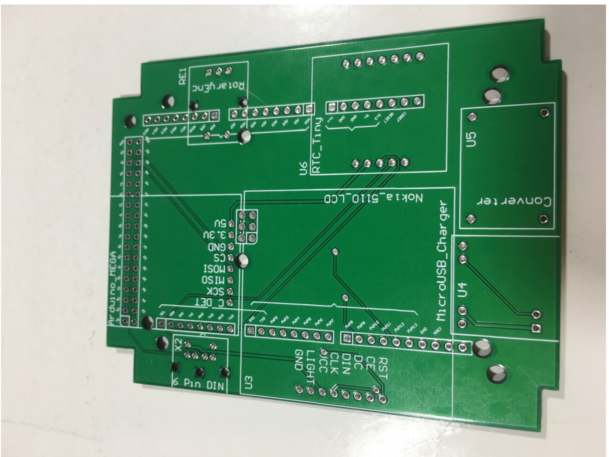

Figure 8.3 – *PCB Top view*

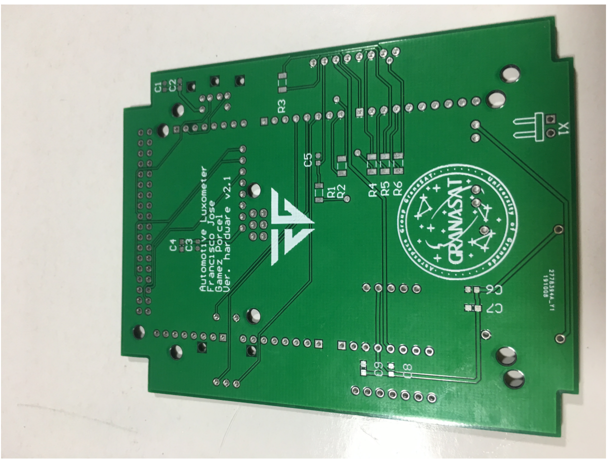

Figure 8.4 – *PCB Botton view*

8.2 Main system assembly

We were already able to assemble the entire device.The components and headers were added to connect the microcontroller.The resistors and capacitors were also added.

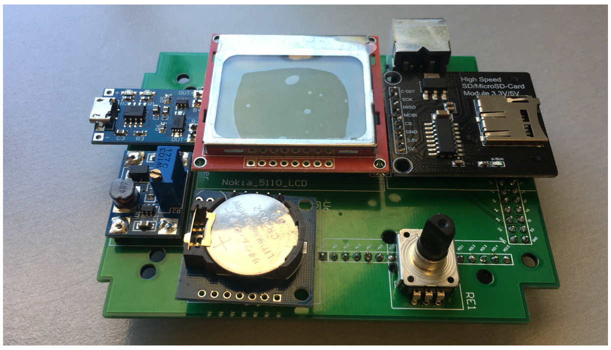

Figure 8.5 – *PCB Top view with components*

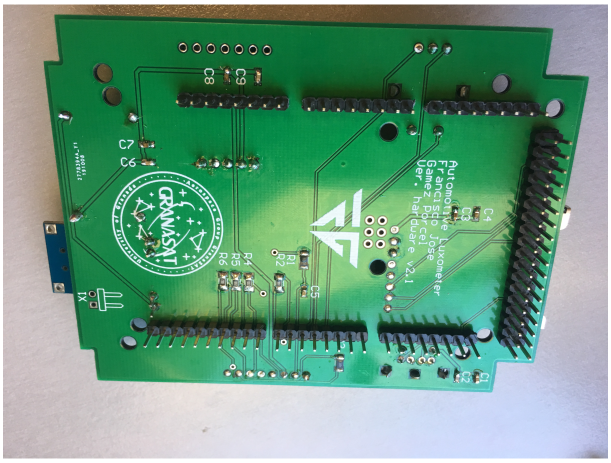

Figure 8.6 – *PCB Bottom view with components*

Then the screws and spacers that attached it to the upper part of the case were placed, leaving the methacrylate protector in the middle.

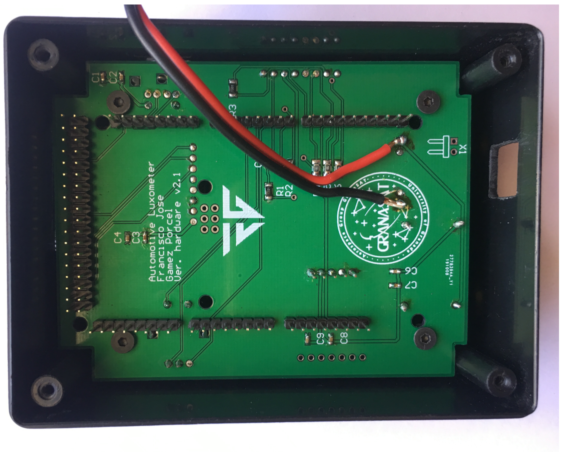

Figure 8.7 – *PCB fixed to the case*

8

Finally the arduino is added.

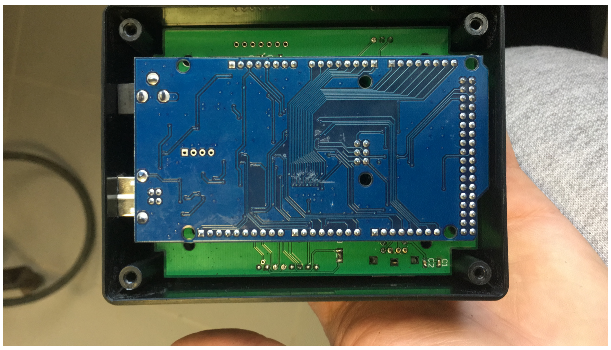

Figure 8.8 – *System with Arduino*

Once assembled, our entire device looks like this:

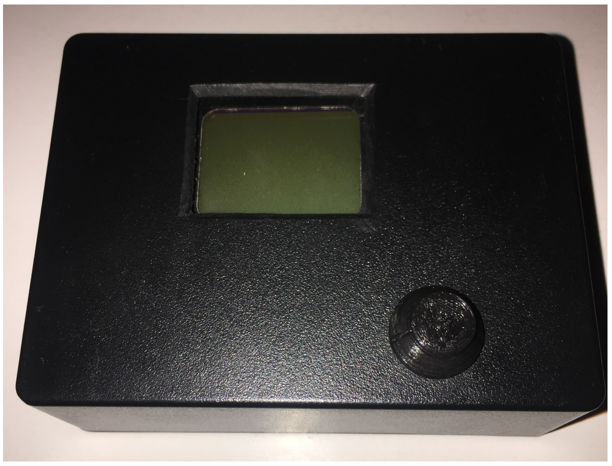

Figure 8.9 – *Complete device*

8.3 Sensor tool manufacturing

From the section 7.10 designs, the files in stl format were exported. and it was printed under the same conditions as shown in the section 6.2.3 obtaining the following pieces.

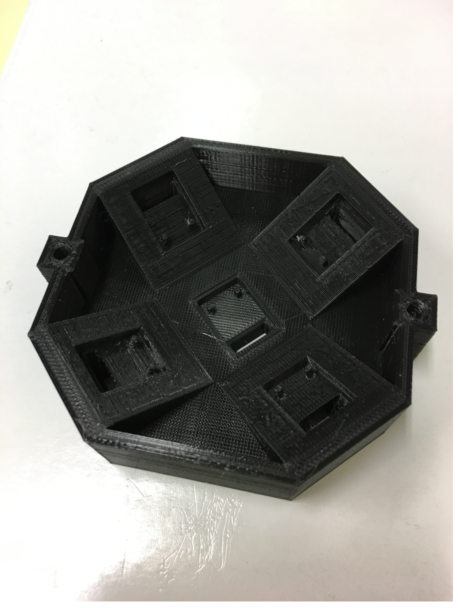

Figure 8.10 – *Sensor suport piece*

8

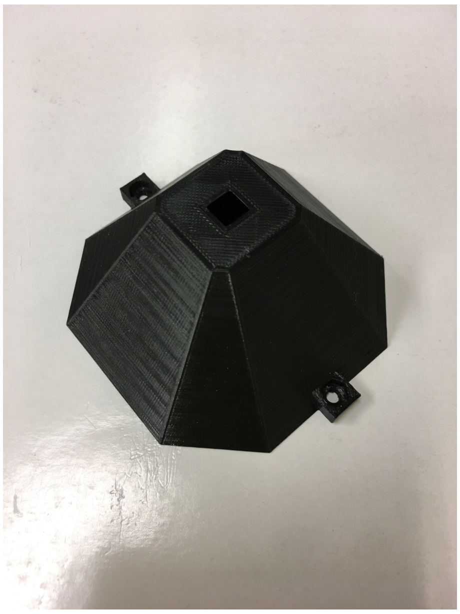

Figure 8.11 – *Sensor bell piece*

Figure 8.12 – *Tool support piece*

8

After having all the main parts printed, we add to the sensor support part the different sensors with their corresponding wiring(figure8.13).Then the nuts were added to the bell of the sensors (figure8.14) and finally the final system was mounted with all its internal wiring(figure8.15).

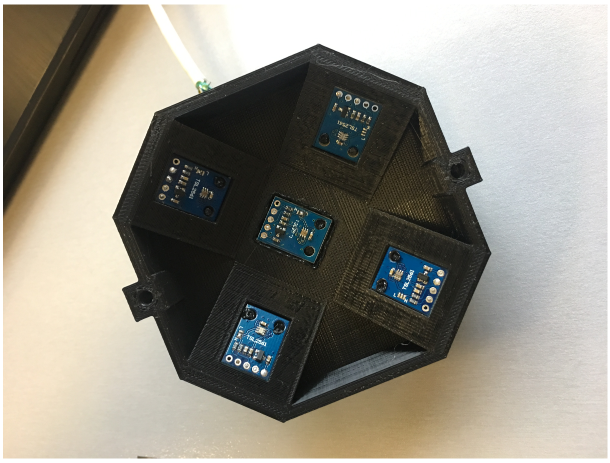

Figure 8.13 – *Wired sensor support with sensor*

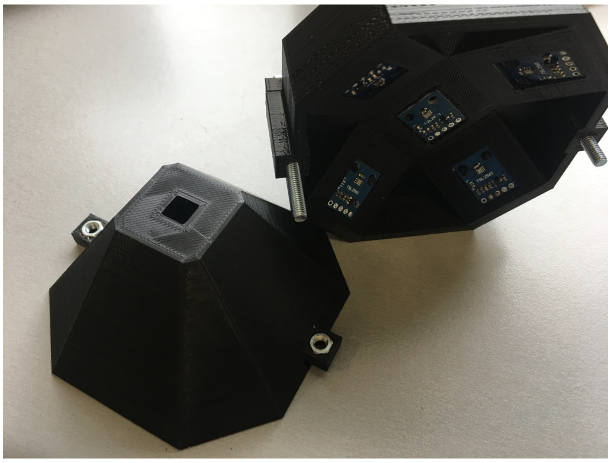

Figure 8.14 – *Complete sensor support and bell with nuts*

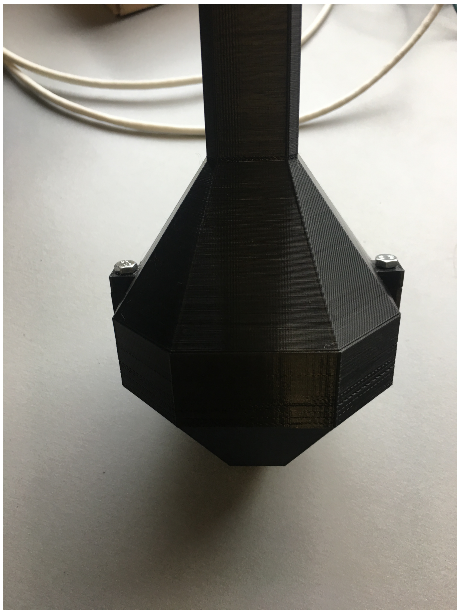

Figure 8.15 – *Complete sensor tool system*

8

Chapter 9

Verification and testing

Finally, since we have all the systems built, it is necessary to assemble them between them and verify that they meet the objectives.

Figure 9.1 – *Main device*

Below we can see the fully assembled system for its operation.

Figure 9.2 – *Main device and sensor tool*

Taking the LEDs that were provided (OOSLON Black Flat figure6.18) to characterize it, we measure to see if they correspond to the values indicated in the data sheet.

Figure 9.3 – *Measure process*

In the case of the OSLON LED with reference LAH9PP we obtain the following results.

Figure 9.4 – *Measure of the LA H9PP*

As we can see we get a reading of 68 lumens.Checking with the data of your data sheet:

LA H9PP

Ordering Information

Type	Luminous Flux [1] I_F = 350 mA Φ_V	Ordering Code
LA H9PP-JXKX-24-1	45 ... 82 lm	Q65111A4306

Figure 9.5 – *Lumens from LA H9PP datasheet*

To make another characterization we use the OSLON LED with reference LR H9PP.

Figure 9.6 – *Measure of the LR H9PP*

We get a 59 lumens reading.Again we check with the results provided by your datasheet.

LR H9PP

Ordering Information

Type	Luminous Flux [1] I_F = 350 mA Φ_V	Ordering Code
LR H9PP-HZJZ-1-1	39 ... 71 lm	Q65111A4286

Figure 9.7 – *Lumens from LR H9PP datasheet*

All these results are performed under the conditions indicated by the manufacturer's datasheet.

9

Chapter 10

Conclusions and future lines

As we have seen in the previous section of results our device responds quite well, coinciding with the technical data provided by the manufacturers.

The system could have been made only with 3 sensors, one central and two lateral, but doing so with 5 sensors gives us greater precision in the final results.

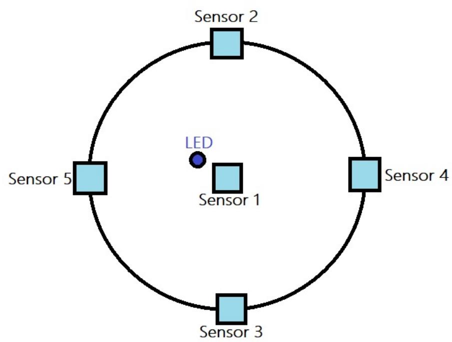

Figure 10.1 – *LED not centered*

We can also say that our system has some tolerance for errors when it comes to perfectly centering the LED at the midpoint of the sensor tool (figure 10.1). This is because as we have placed a central sensor and four lateral sensors, the non-centering of the LED can influence the measurement of the central sensor but the differences between the lateral sensors are compensated since they have the same contribution factor over the final measurement.

This can be done since in our considerations we have taken the radiation pattern as a Lambertian emitter (see fig10.2). In addition, in the data sheet of the LEDs that we have characterized for our system, it indicates this.

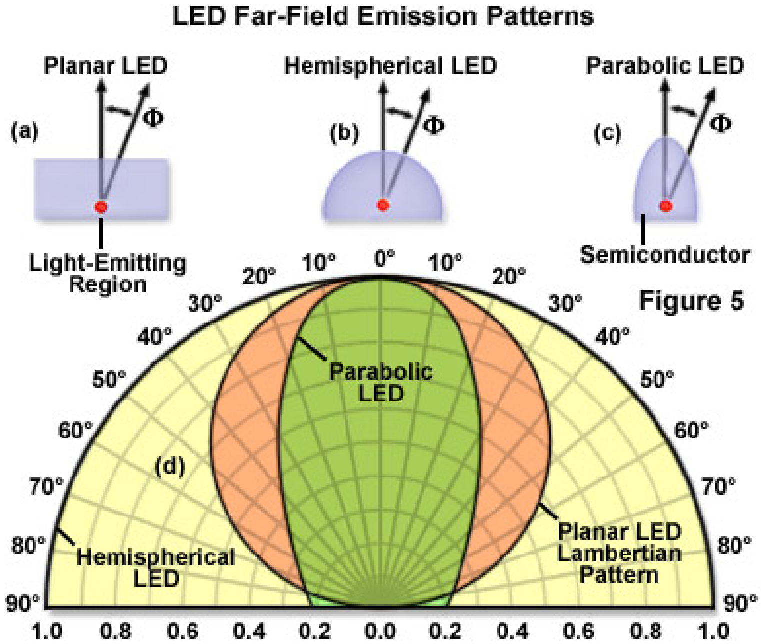

Figure 10.2 – *LED radiation patterns [12]*

This project may have derivative projects based on the need to adapt the same system to different LEDs or lighting sources with different radiation diagrams (not Lambertians), in large part that would be done by modifying the programming based on an extensive study with different LEDs calibrated to draw correct conclusions.

In addition, different types of sensor tools can be developed based on the different working conditions for which the project is focused, that is to change size, possible arrangement and manufacture of the sensors to reduce the size to the maximum.

In this area, a very interesting proposal would be to make a single circuit to accommodate all sensors made of flexible materials (fig 10.3)such as those that have been developed in recent years (flexible PCB) and put on it the sensor itself.

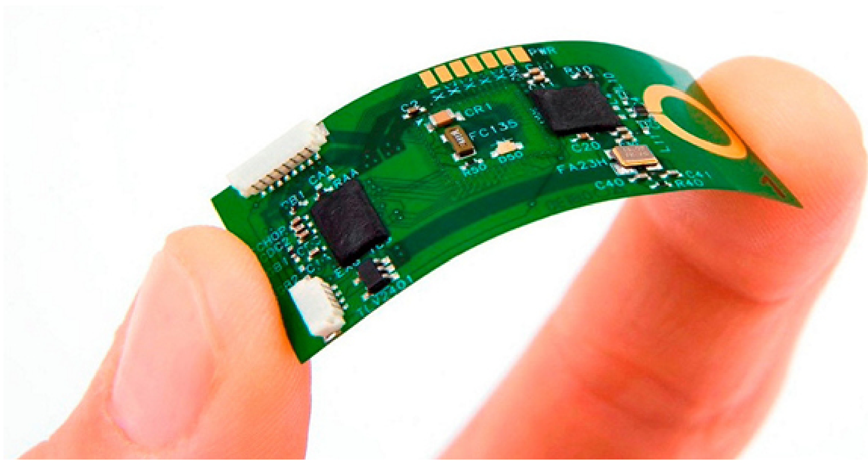

Figure 10.3 – *LED radiation patterns [13]*

Below are some improvements that began to develop but have not been implemented.

10.1 Power switch

In order to remove the switch to turn the device on and off, it was thought to use the same rotary button so that, by pressing and holding the button a few seconds, the device could be turned on and off.

This idea began to be developed but it was not implemented because the PCB had already been printed and this meant a reprint of it to make the necessary changes in it.

Next we see the circuit that had been developed and had been introduced in the schematic of the project for this purpose.

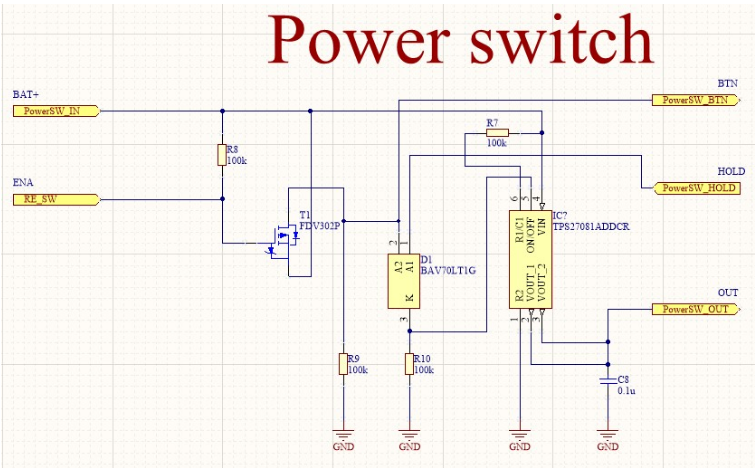

Figure 10.4 – *Power switch schematic*

10.2 Pooling to interrupt programation

Our system was initially designed for the reading of any change in the rotary button to be performed by pooling, this means that it complies with the reading of the rotary when it corresponds to it within the function.

As a result, this may result in readings of the button that are not read causing the device to behave badly in the face of its reading.

To solve this, it was planned to program it with external interruptions of the microcontroller, with this it was achieved that the reading of the rotary button was prioritized before any part of the program and then the program where it had been interrupted was continued.

We could not do this because we already had the PCB printed and our rotary button terminals were not connected to microcontroller ports that supported external interruptions.

Chapter 11

Project budget

Design of a characterization system for automotive LEDs

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633461732
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11/20/2019

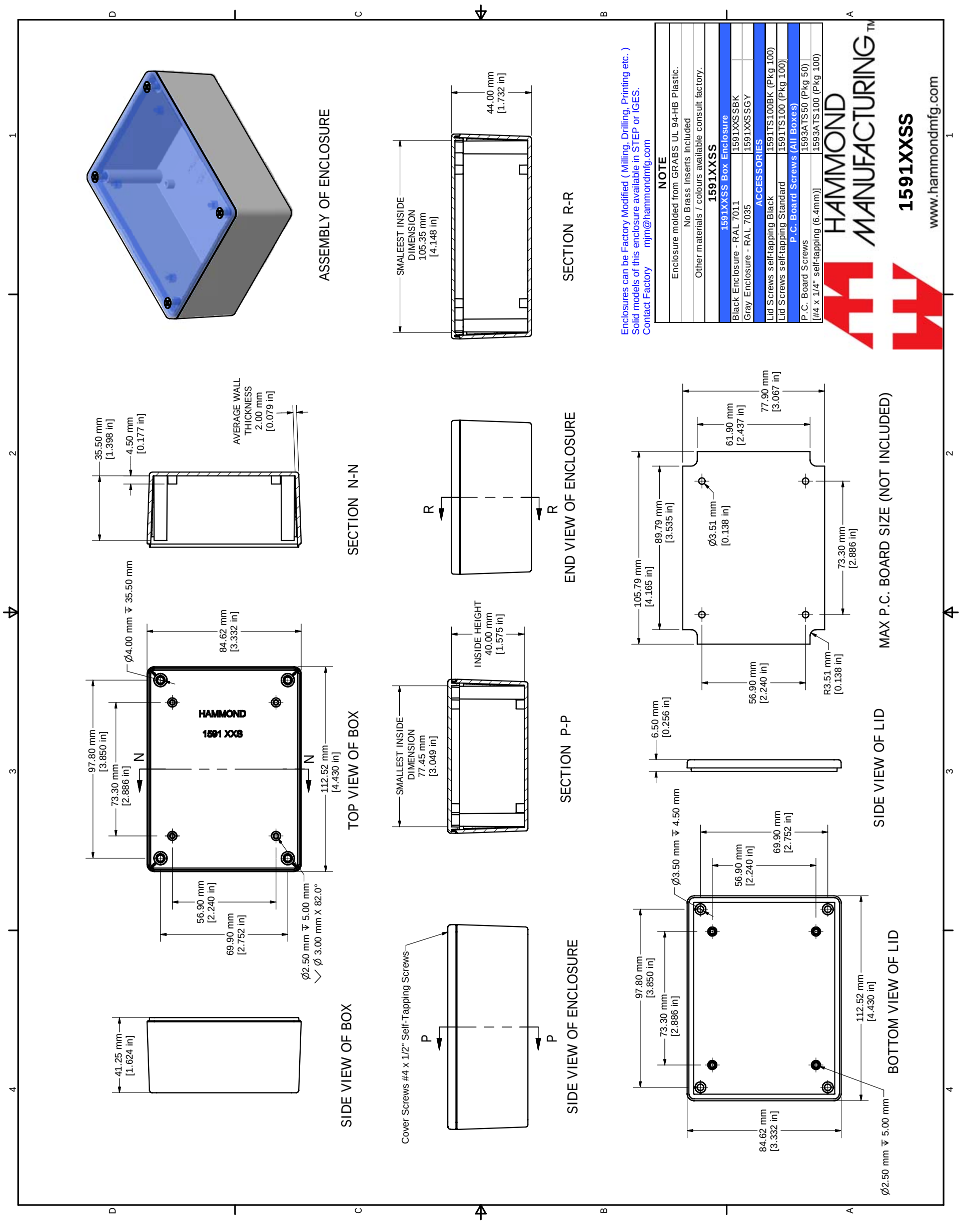
Project budget

DESCRIPTION	QTY	UNIT PRICE	TOTAL
Case ABS Hammond 1591XXSSBK, 1591, IP54, 112.5 x 84.6 x 41.3m	1	4.32 €	4.32 €
Female connector DIN Mini 6 pines, 1A, 30 V ac	1	1.59 €	1.59 €
Rotary Encoder Alps Alpine, 24 Flat Pulse, Through Hole Mount	1	1.28 €	1.28 €
Filament 3D printer PLA 1,75mm	0.381	10.90 €	4.15 €
TSL2561 Luminosity sensor	5	3.70 €	18.50 €
LCD5110 84x48	1	2.74 €	2.74 €
Robodyn MicroSD/SD High Speed Module	1	2.15 €	2.15 €
Li-Po 3.7V Battery	1	4.77 €	4.77 €
RTC DS1307	1	0.97 €	0.97 €
PCB Board JLCPCB	1	3.07 €	3.07 €
MicroUSB Charger Module Arduino	1	1.55 €	1.55 €
Mega 2560 r3	1	8.09 €	8.09 €
TZT 2-24V a 2-28V 2A DC-DC SX1308	1	0.97 €	0.97 €
6 Wire Data Cable	2	1.00 €	2.00 €
2.54mm Male PCB Header 40 pin String	1	1.76 €	1.76 €
2.54mm Female PCB Header 40 pin String	1	1.06 €	1.06 €
M.3 Screw	8	0.03 €	0.24 €
M.3 Hex Nut	4	0.05 €	0.20 €
0603 SMD Ceramic Capacitors 100nF	0.05	0.79 €	0.04 €
Cap Ceramic 1uF 16VDC X5R 10% SMD 0603	0.05	0.67 €	0.03 €
SMD Resistor RK73H2BTTD1504F SMD Resistor 10kOhm	0.1	0.60 €	0.06 €
Acrylic methacrylate 3mm 200mm x 200mm	1	12.30 €	12.30 €
Small signal diode BAS21 0.2A 250V	1	0.05 €	0.05 €
Power switch	1	0.50 €	0.50 €
Black/Red wire pair	1	6.14 €	6.14 €
HUMAN RESOURCES AND INFRASTRUCTURE COSTS			
Electronic engineer	400	20.00 €	8,000.00 €
Project supervisor	80	35.00 €	2,800.00 €
Laboratory rent/day	60	50.00 €	3,000.00 €
PROGRAMS AND LICENSES			
SolidWorks CAD 3D License 2019	1	1,010.00 €	1,010.00 €
Altium Designer 2019 License	1	7,430.00 €	7,430.00 €

SUBTOTAL	78.54
DISCOUNT	0.00
SUBTOTAL LESS DISCOUNT	78.54
TAX RATE	21.00%
TOTAL TAX	16.49
SHIPPING/HANDLING	11.00
Material Total	**106.03 €**
Software Total	**8,440.00 €**
HR & IC	**13,800.00 €**
Project Total	**22,346.03 €**

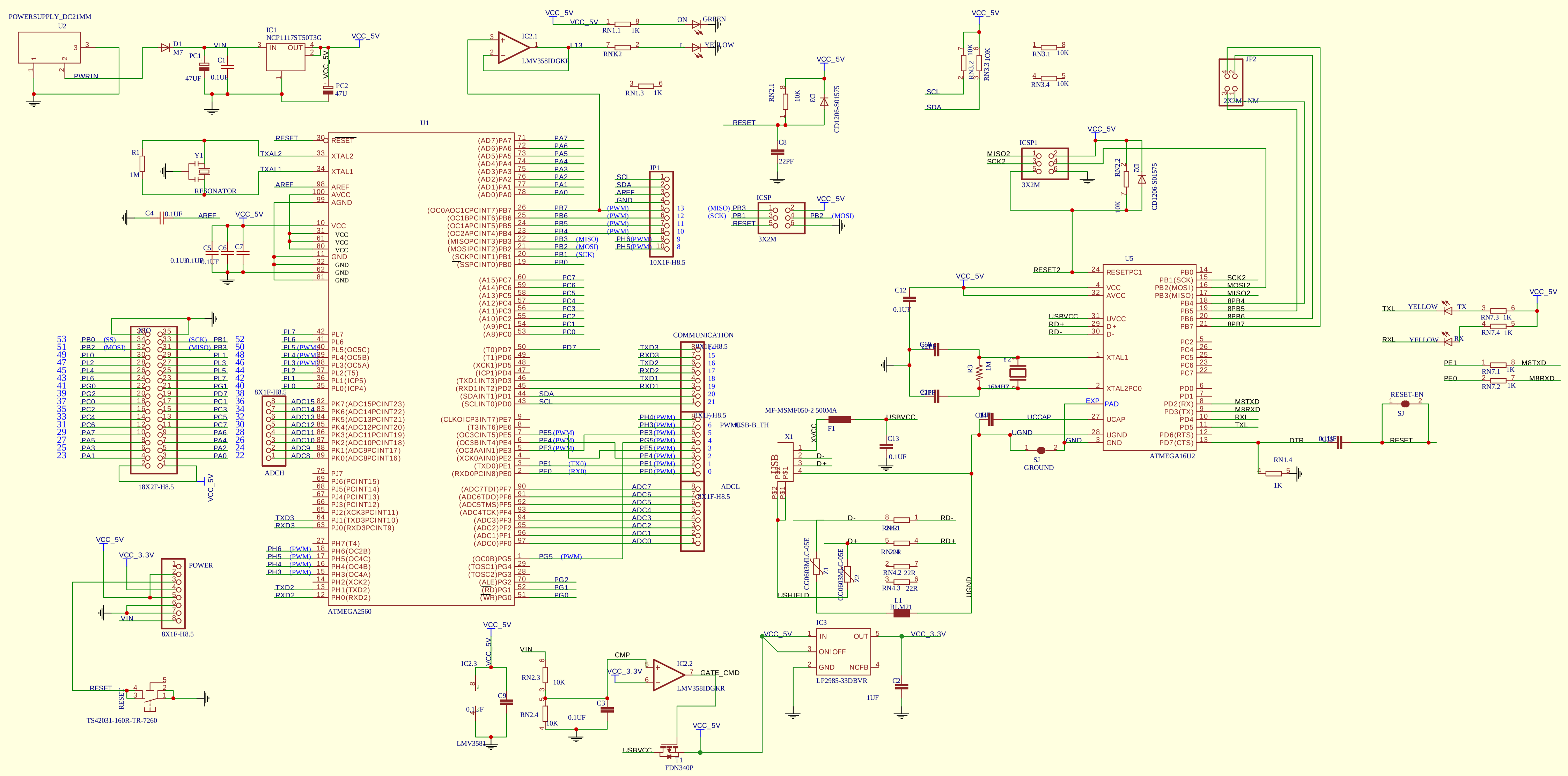
Appendix A

Hammond 1591XXS Datasheet



Appendix B

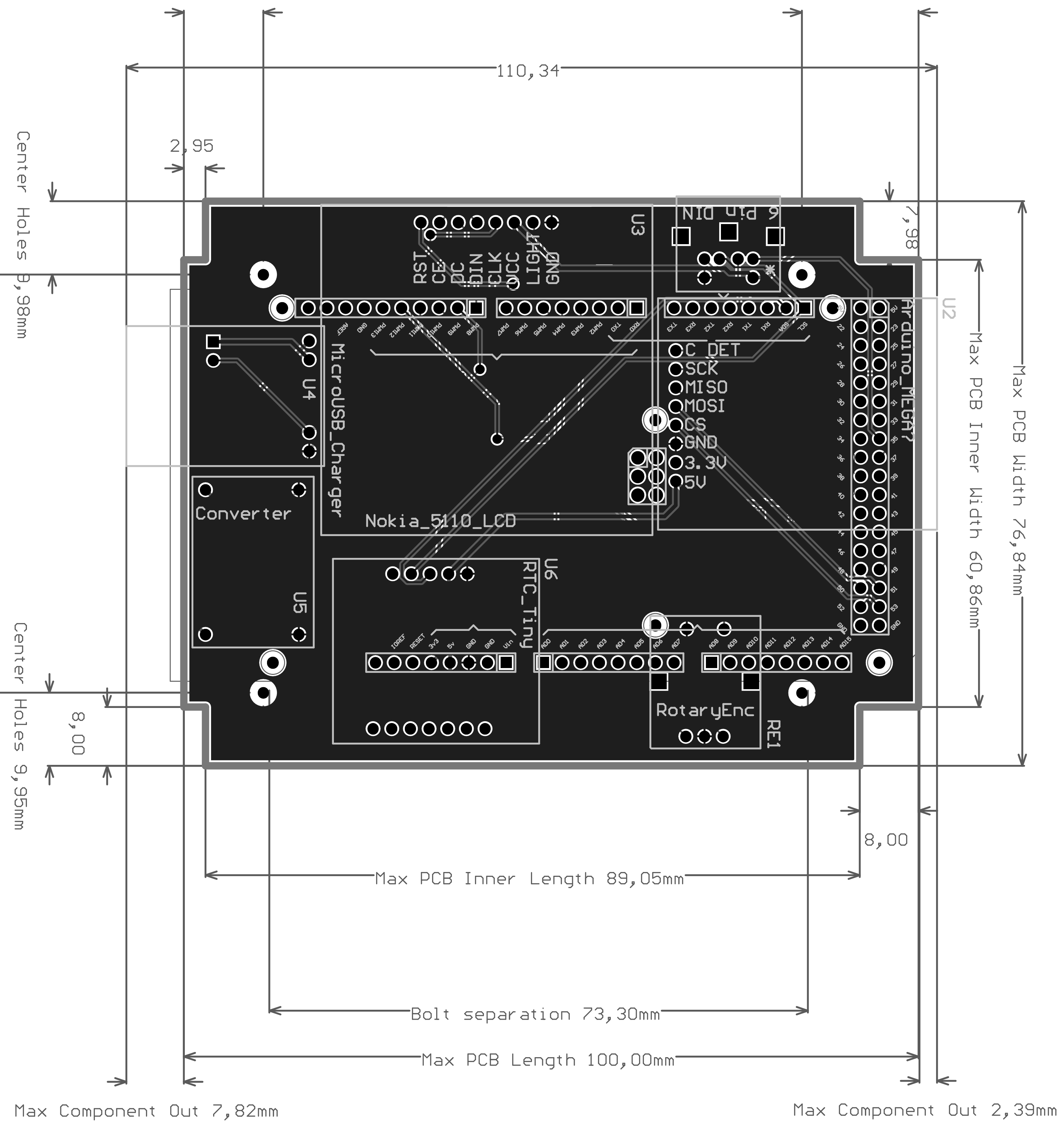
Arduino Mega 2560

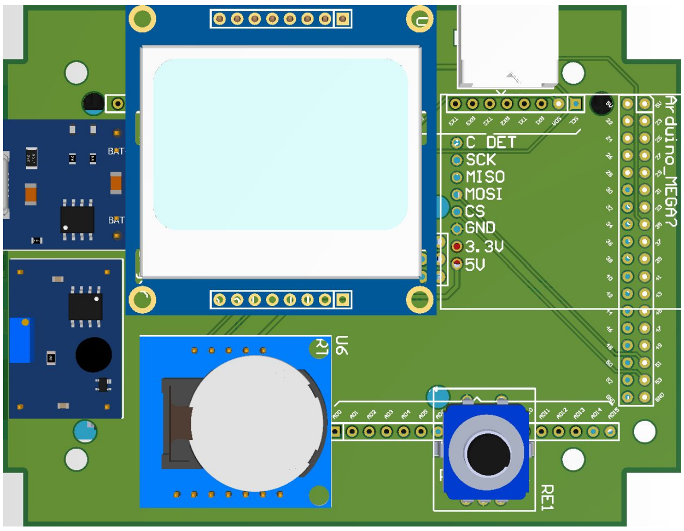


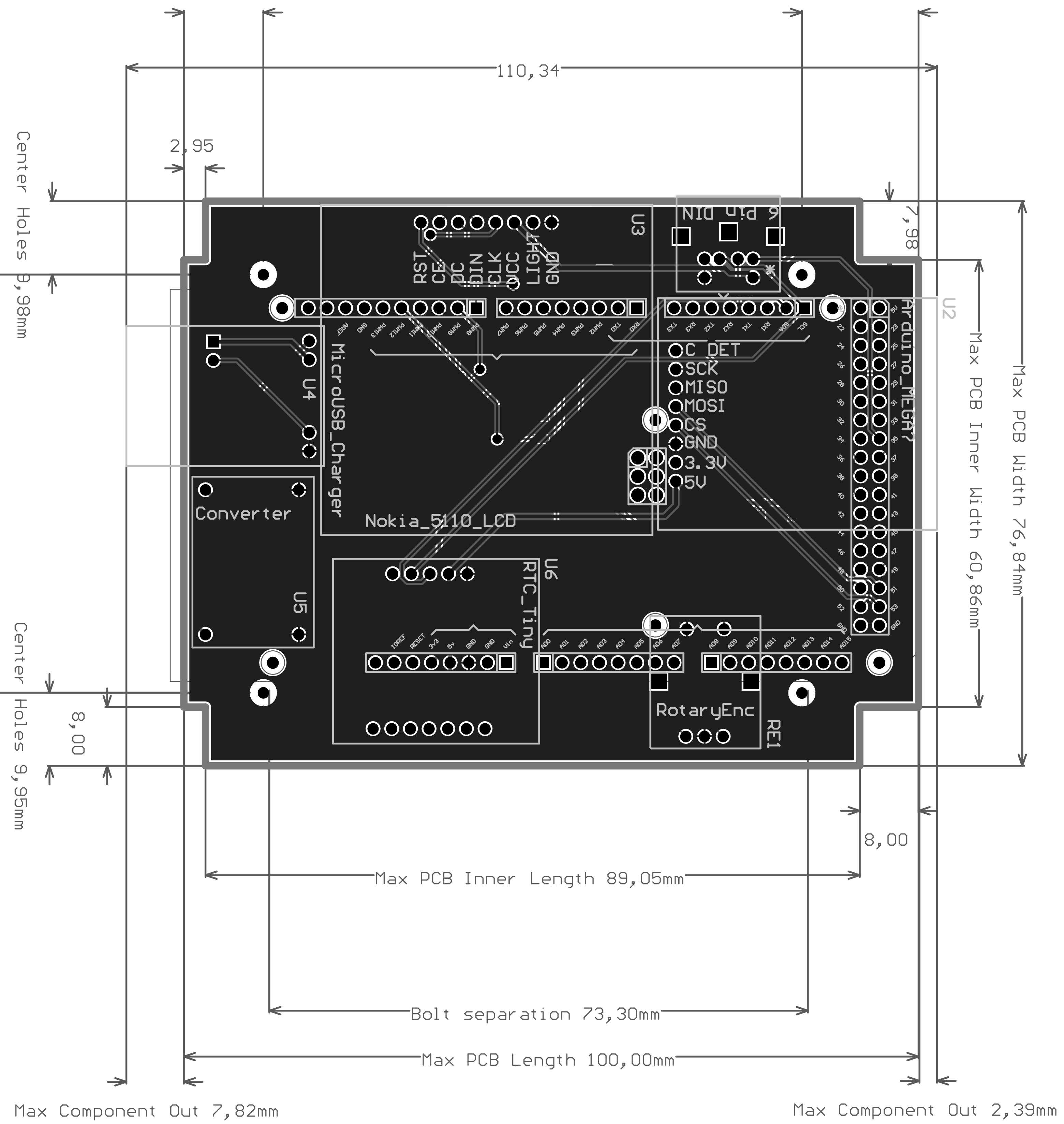
POWERSUPPLY_DC21MM
U2
PWRIN
D1
M7
VIN
PC1
47UF
C1
0.1UF
IC1
NCP1117ST50T3G
IN
OUT
VCC_5V
PC2
47U
U1
ATMEGA2560
RESET
XTAL2
XTAL1
AREF
AVCC
AGND
VCC
GND
R1
1M
Y1
RESONATOR
C4
0.1UF
C5
C6
C7
IC2.1
LMV358IDGKR
RN1.1
1K
ON
GREEN
RN1.2
L
YELLOW
L13
RN1.3
JP1
10X1F-H8.5
SCL
SDA
18X2F-H8.5
8X1F-H8.5
ADCH
COMMUNICATION
PWML
ADCL
POWER
VCC_3.3V
TS42031-160R-TR-7260
IC2.3
LMV358I
C9
RN2.3
RN2.4
10K
C3
CMP
IC2.2
LMV358IDGKR
GATE_CMD
USBVCC
T1
FDN340P
IC3
LP2985-33DBVR
ON!OFF
NCFB
C2
1UF
X1
USB-B_TH
USB
F1
MF-MSMF050-2 500MA
XVCC
C13
0.1UF
Z1
Z2
CG0603MLC-05E
L1
BLM21
USHIELD
UGND
RN2.1
C8
22PF
D3
CD1206-S01575
ICSP
3X2M
ICSP1
RN2.2
D2
RESET2
U5
ATMEGA16U2
RESETPC1
UVCC
UCAP
XTAL2PC0
C12
C10
C11
22PF
R3
Y2
16MHZ
C14
SJ
GROUND
RN1.4
DTR
RESET-EN
JP2
2X2M-NM
RN3.1
RN3.2
RN3.3
RN3.4
RN7.1
RN7.2
RN7.3
RN7.4
TXL
RXL
TX
RX
PE1
PE0
M8TXD
M8RXD

Appendix C

PCB Design output files


110,34
2,95
Center Holes 9,98mm
Center Holes 9,95mm
7,98
8,00
8,00
Max PCB Width 76,84mm
Max PCB Inner Width 60,86mm
Max PCB Inner Length 89,05mm
Bolt separation 73,30mm
Max PCB Length 100,00mm
Max Component Out 7,82mm
Max Component Out 2,39mm
6 Pin DIN
U3
RST
CE
DC
DIN
CLK
VCC
LIGHT
GND
U2
Arduino_MEGA2
U4
MicroUSB_Charger
Nokia_5110_LCD
C_DET
SCK
MISO
MOSI
CS
GND
3.3V
5V
Converter
U5
U6
RTC_Tiny
RotaryEnc
RE1


C_DET
SCK
MISO
MOSI
CS
GND
3.3V
5V
Arduino_MEGA2
U6
RE1
BAT
BAT



110,34
2,95
Center Holes 9,98mm
Center Holes 9,95mm
7,98
8,00
8,00
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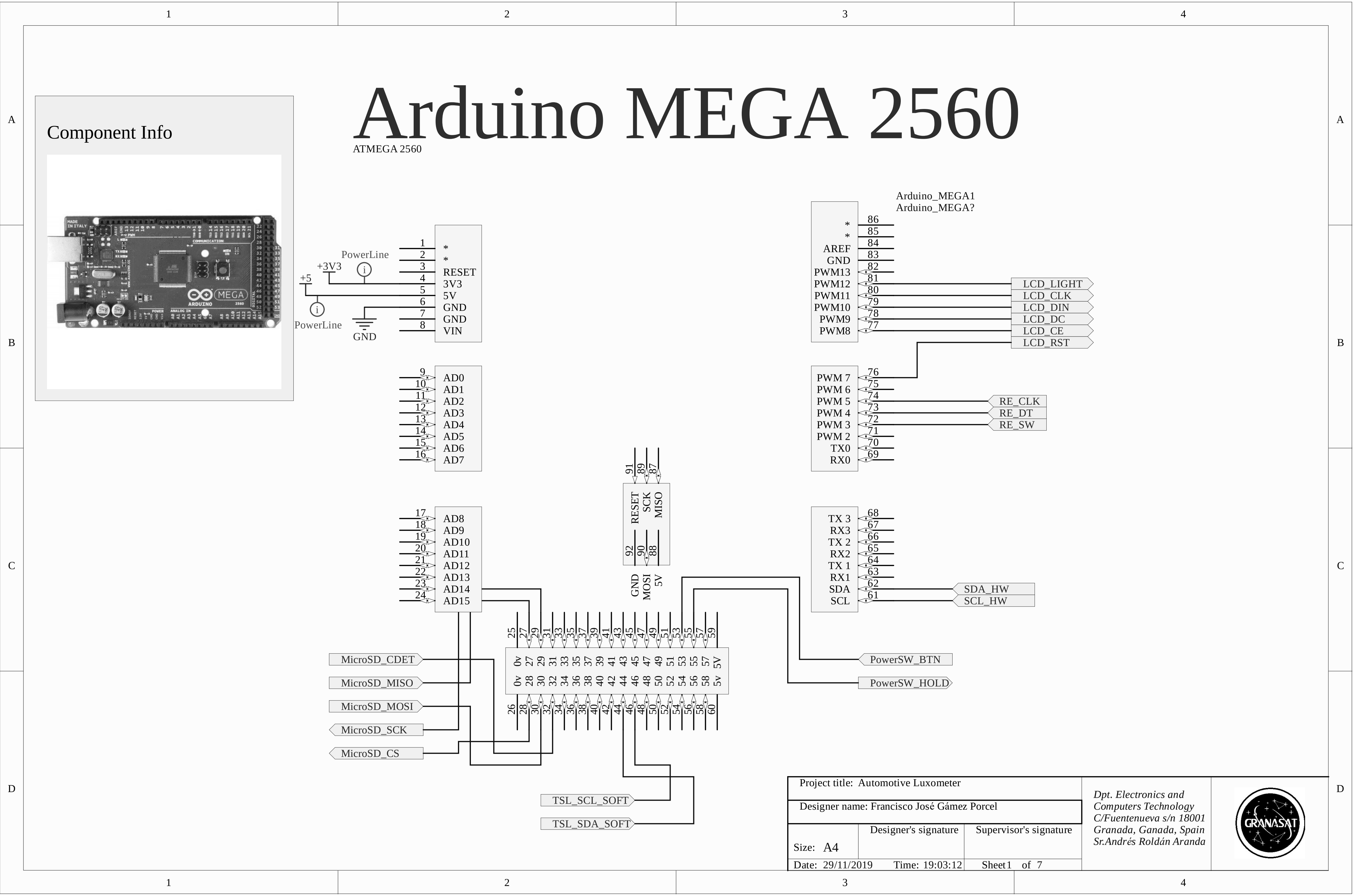
6 Pin DIN
U3
RST
CE
DC
DIN
CLK
VCC
LIGHT
GND
U2
Arduino_MEGA2
U4
MicroUSB_Charger
Nokia_5110_LCD
SD_DET
SCK
MISO
MOSI
CS
GND
3.3V
5V
Converter
U5
U6
RTC_Tiny
RotaryEnc
RE1



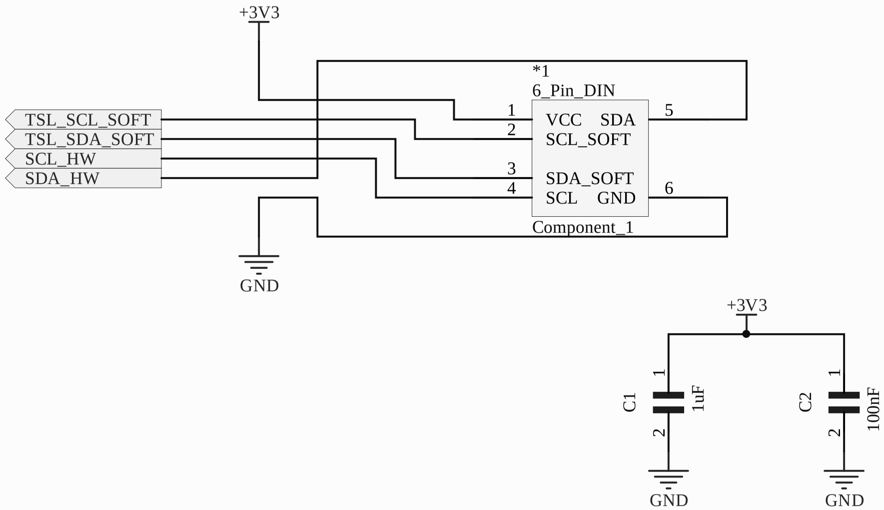
Arduino MEGA 2560
ATMEGA 2560
Component Info
Arduino_MEGA1
Arduino_MEGA?
PowerLine
+3V3
+5
PowerLine
GND
*
*
RESET
3V3
5V
GND
GND
VIN
AD0
AD1
AD2
AD3
AD4
AD5
AD6
AD7
AD8
AD9
AD10
AD11
AD12
AD13
AD14
AD15
RESET
SCK
MISO
GND
MOSI
5V
AREF
GND
PWM13
PWM12
PWM11
PWM10
PWM9
PWM8
PWM 7
PWM 6
PWM 5
PWM 4
PWM 3
PWM 2
TX0
RX0
TX 3
RX3
TX 2
RX2
TX 1
RX1
SDA
SCL
LCD_LIGHT
LCD_CLK
LCD_DIN
LCD_DC
LCD_CE
LCD_RST
RE_CLK
RE_DT
RE_SW
SDA_HW
SCL_HW
PowerSW_BTN
PowerSW_HOLD
MicroSD_CDET
MicroSD_MISO
MicroSD_MOSI
MicroSD_SCK
MicroSD_CS
TSL_SCL_SOFT
TSL_SDA_SOFT
Project title: Automotive Luxometer
Designer name: Francisco José Gámez Porcel
Designer's signature
Supervisor's signature
Size: A4
Date: 29/11/2019
Time: 19:03:12
Sheet1 of 7
Dpt. Electronics and
Computers Technology
C/Fuentenueva s/n 18001
Granada, Ganada, Spain
Sr.Andrés Roldán Aranda
GRANASAT

I2C_Sensors

Component Info

Sensors details

I2C Adress
0x29
0x39
0x49
Soft I2C Adress



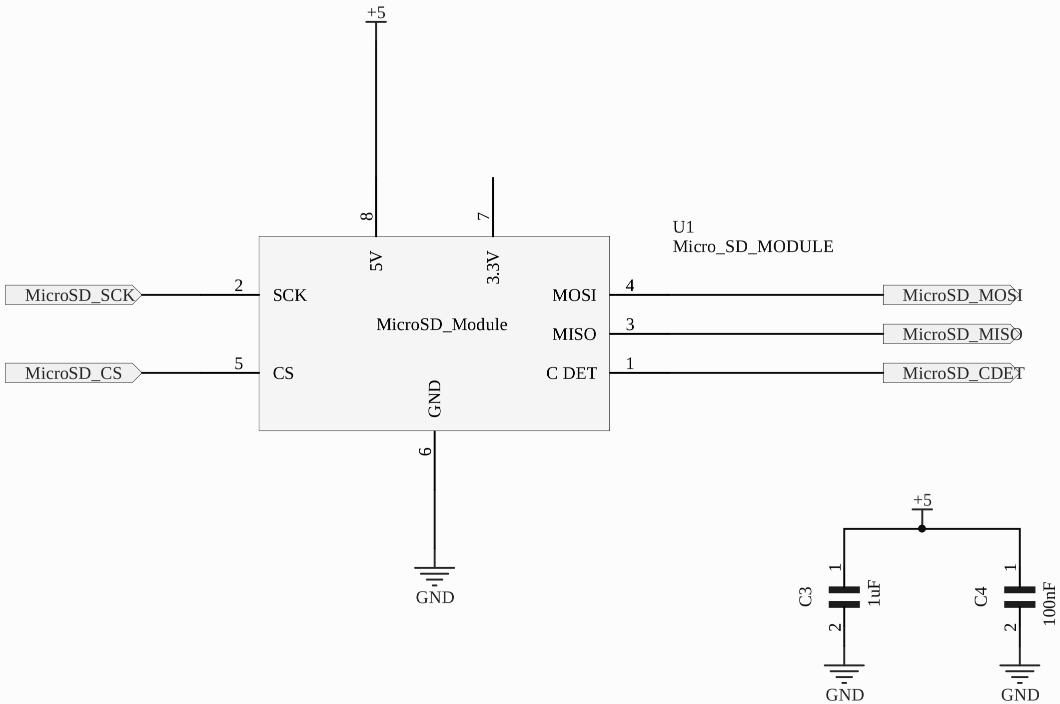
Project title: Automotive Luxometer		
Designer name: Francisco José Gámez Porcel		
Size: A4	Designer's signature	Supervisor's signature
Date: 29/11/2019	Time: 19:03:12	Sheet6 of 7

Dpt. Electronics and Computers Technology
C/Fuentenueva s/n 18001
Granada, Ganada, Spain
Sr.Andrés Roldán Aranda

MicroSD_Module

Component Info

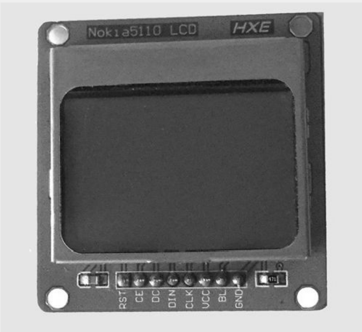
Supports MicroSD and SD.



Project title: Automotive Luxometer			*Dpt. Electronics and Computers Technology C/Fuentenueva s/n 18001 Granada, Ganada, Spain Sr.Andrés Roldán Aranda*
Designer name: Francisco José Gámez Porcel			
Size: A4	Designer's signature	Supervisor's signature	
Date: 29/11/2019	Time: 19:03:13	Sheet5 of 7	

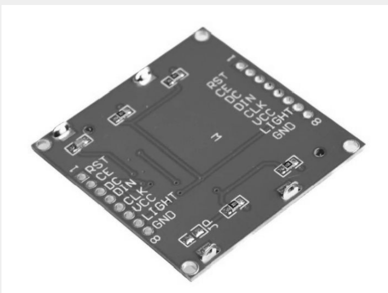
NOKIA 5110_LCD

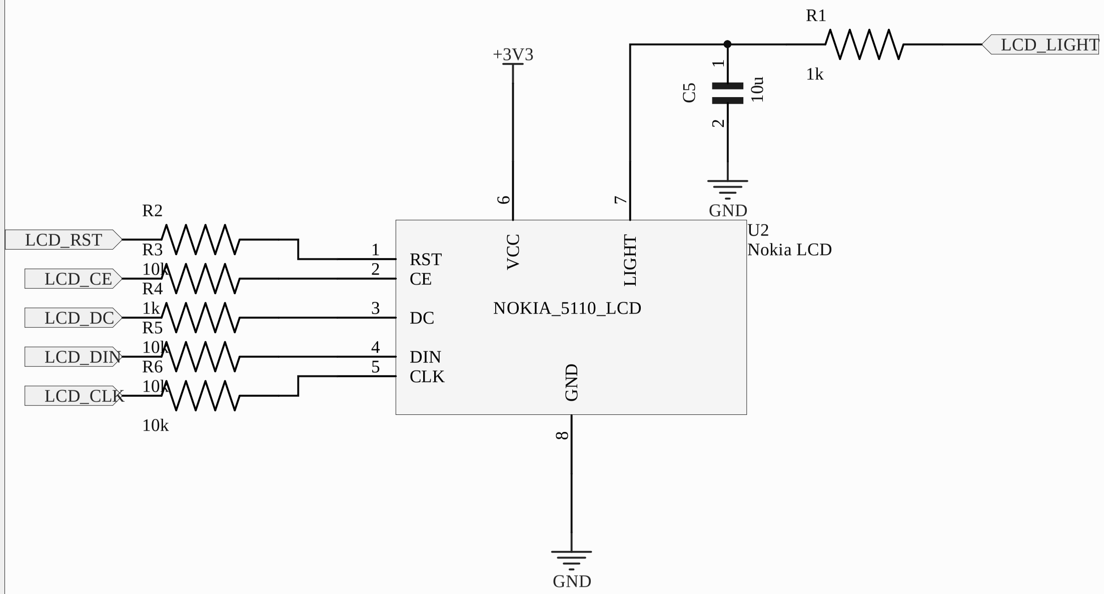
Component Info



Added Resistors to digital pins
for protecting LCD

R1 C5 -> LPF for setting the backlight
from PWM signal pin

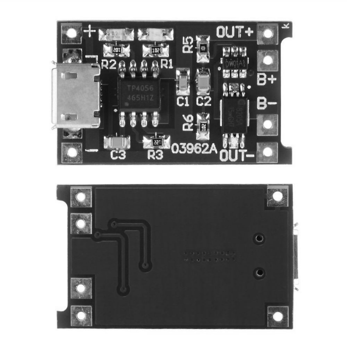




Project title: Automotive Luxometer			*Dpt. Electronics and Computers Technology C/Fuentenueva s/n 18001 Granada, Ganada, Spain Sr.Andrés Roldán Aranda*
Designer name: Francisco José Gámez Porcel			
Size: A4	Designer's signature	Supervisor's signature	
Date: 29/11/2019	Time: 19:03:13	Sheet2 of 7	

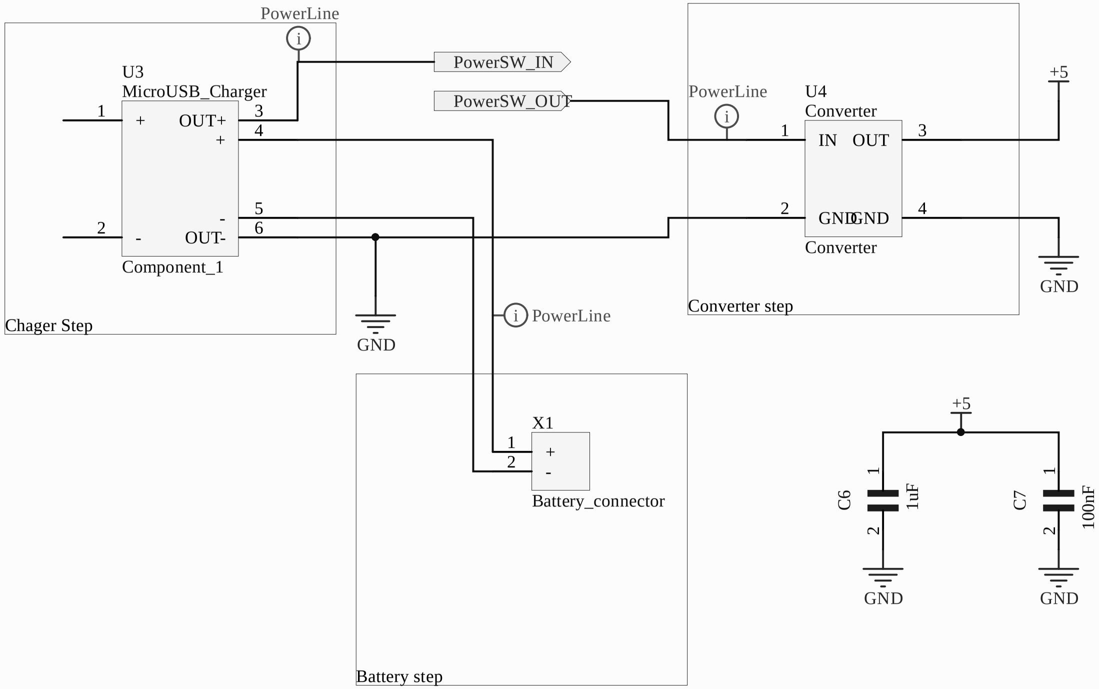
Component Info

Micro USB Charger



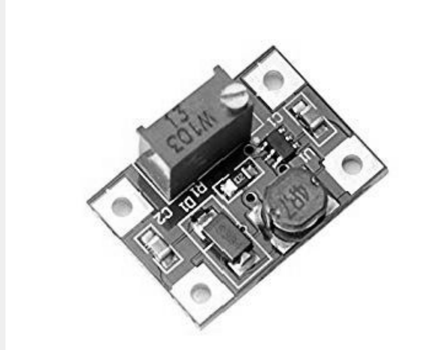
Características:

-Voltaje de entrada: 4,5-5,5 V
-rotección Sobretensión: 4,2 V
-Protección Sobredescarga: 2,4V
-Corriente de salida máxima (para carga de baterías): 1A
-Protección de Sobrecorriente (al circuito a alimentar): 3A
-Indicador de Carga: el led cambia de color al estar la batería completamente cargada.
-Interfaz de entrada: Mini USB o Cable soldado.
-Salida independiente para la carga y la batería



Component Info

DC-DC Converter

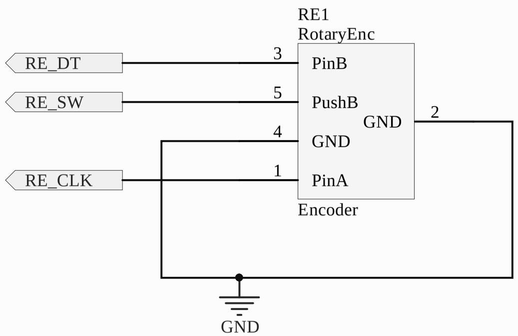


Maximum Input Voltage: DC 2 - 24 V
Maximum Output Voltage: DC 2 - 28 V
máx current output: 2 Osc frec
1.2 MHz efficiency: 95% pot 10 K to adjust,

Project title: Automotive Luxometer		*Dpt. Electronics and Computers Technology C/Fuentenueva s/n 18001 Granada, Ganada, Spain Sr.Andrés Roldán Aranda*
Designer name: Francisco José Gámez Porcel		
Size: A4	Designer's signature	Supervisor's signature
Date: 29/11/2019	Time: 19:03:14	Sheet7 of 7

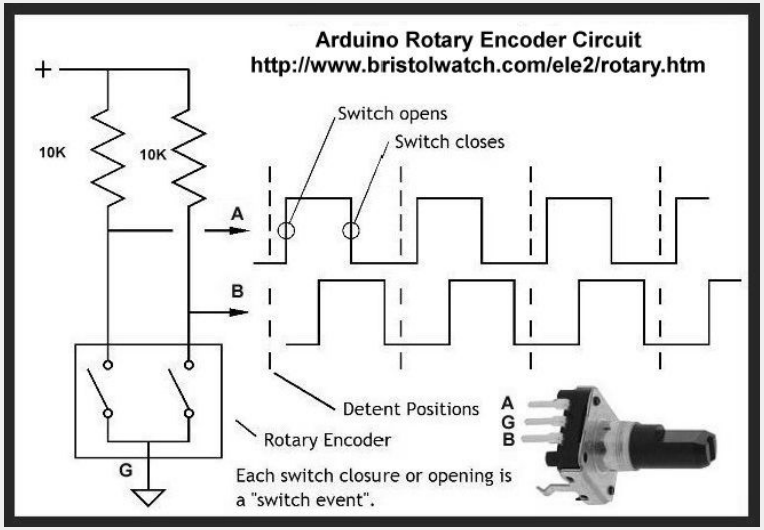
Rotary Encoder

Component Info



How does it works

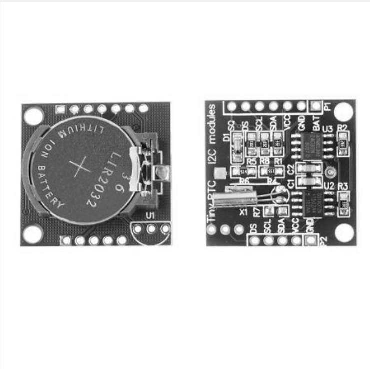
Input pullup resistors setted via software



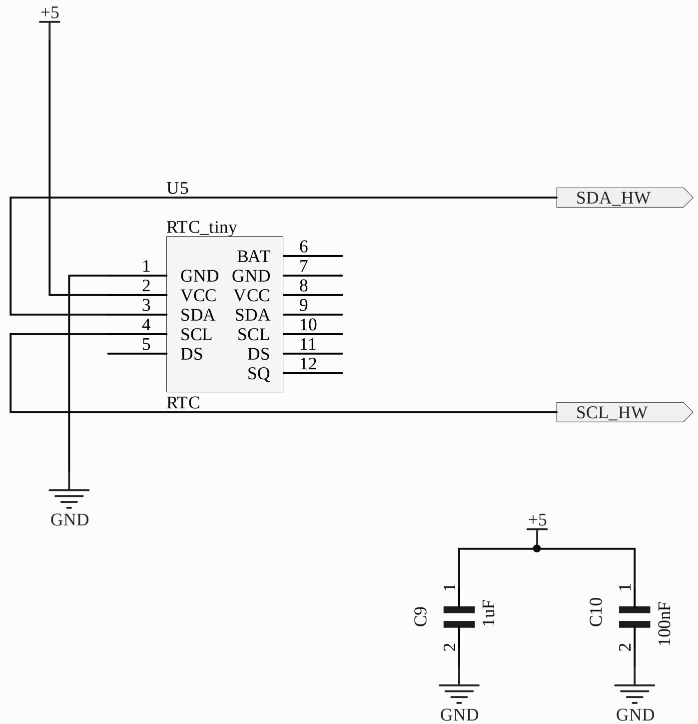
Project title: Automotive Luxometer			*Dpt. Electronics and Computers Technology C/Fuentenueva s/n 18001 Granada, Ganada, Spain Sr.Andrés Roldán Aranda*
Designer name: Francisco José Gámez Porcel			
Size: A4	Designer's signature	Supervisor's signature	
Date: 29/11/2019	Time: 19:03:14	Sheet3 of 7	

RTC

Component Info

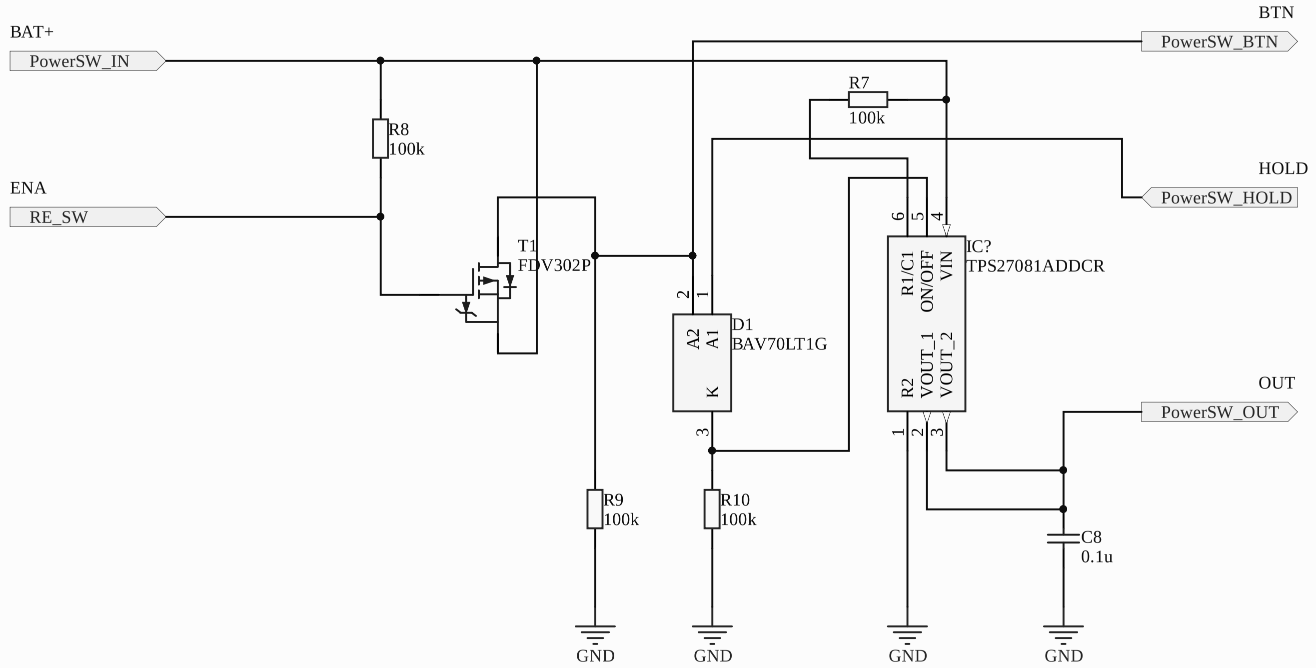


I2C Adress
0x68



Project title: Automotive Luxometer		*Dpt. Electronics and Computers Technology C/Fuentenueva s/n 18001 Granada, Ganada, Spain Sr.Andrés Roldán Aranda*	
Designer name: Francisco José Gámez Porcel			
Size: A4	Designer's signature	Supervisor's signature	
Date: 29/11/2019	Time: 19:03:14	Sheet4 of 7	

Power switch



Component Info

This module allow to power on and power off Arduino holding pressed a button
HOLD pin must be HIGH to keep power ON the Arduino
ENA must be connected to the pushbutton desired

Project title: Automotive Luxometer		
Designer name: Francisco José Gámez Porcel		
Size: A4	Designer's signature	Supervisor's signature
Date: 29/11/2019	Time: 19:03:15	Sheet* of *

Dpt. Electronics and Computers Technology
C/Fuentenueva s/n 18001
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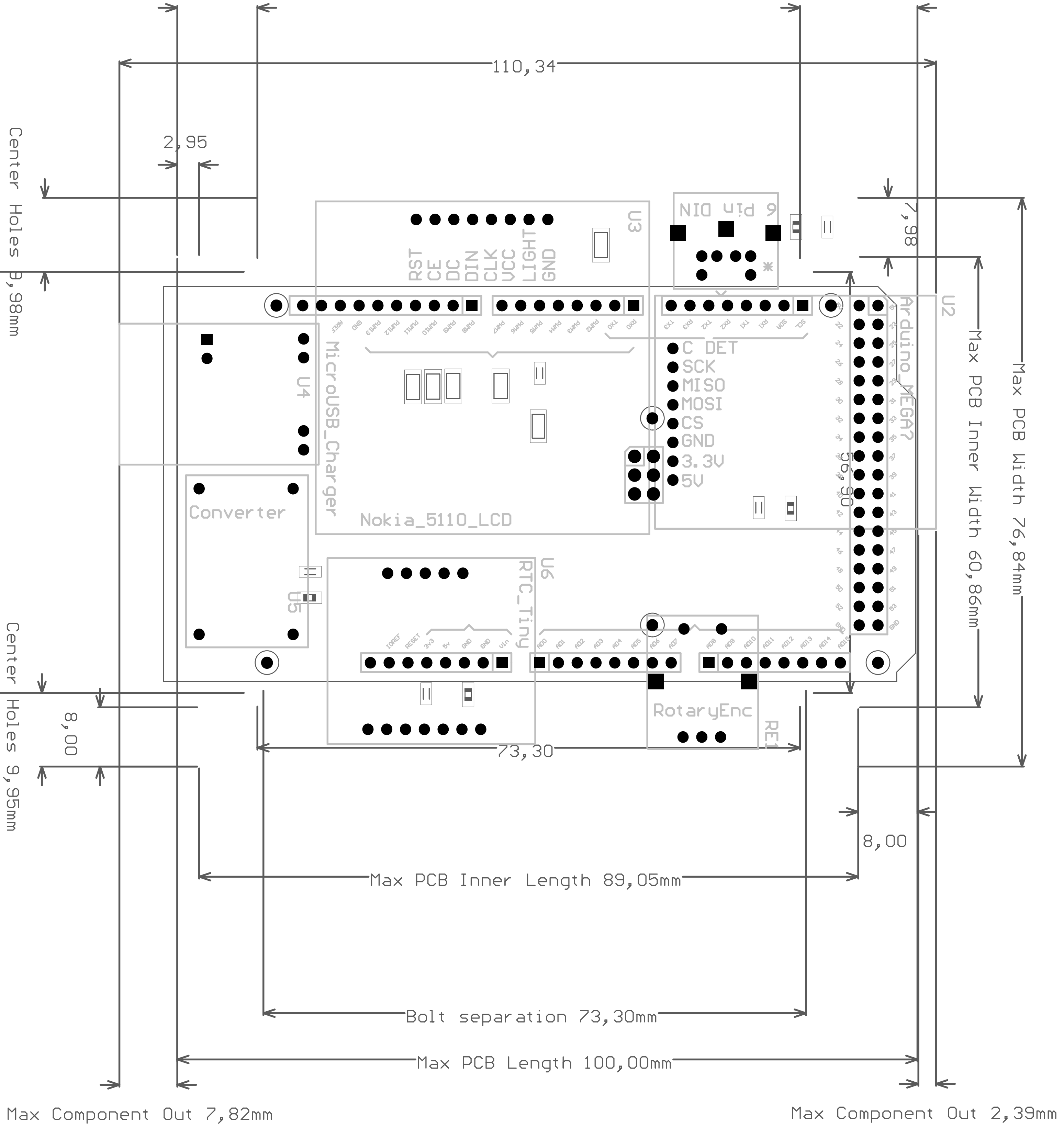
Sr.Andrés Roldán Aranda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Center Holes 9,98mm
7,98
Max PCB Width 76,84mm
Max PCB Inner Width 60,86mm
U3
RST
CE
DC
DIN
CLK
VCC
LIGHT
GND
6 Pin DIN
U2
Arduino_MEGA2
MicroUSB_Charger
U4
C DET
SCK
MISO
MOSI
CS
GND
3.3V
5V
56,90
Converter
Nokia_5110_LCD
U5
U6
RTC_Tiny
RotaryEnc
RE1
Center Holes 9,95mm
8,00
73,30
8,00
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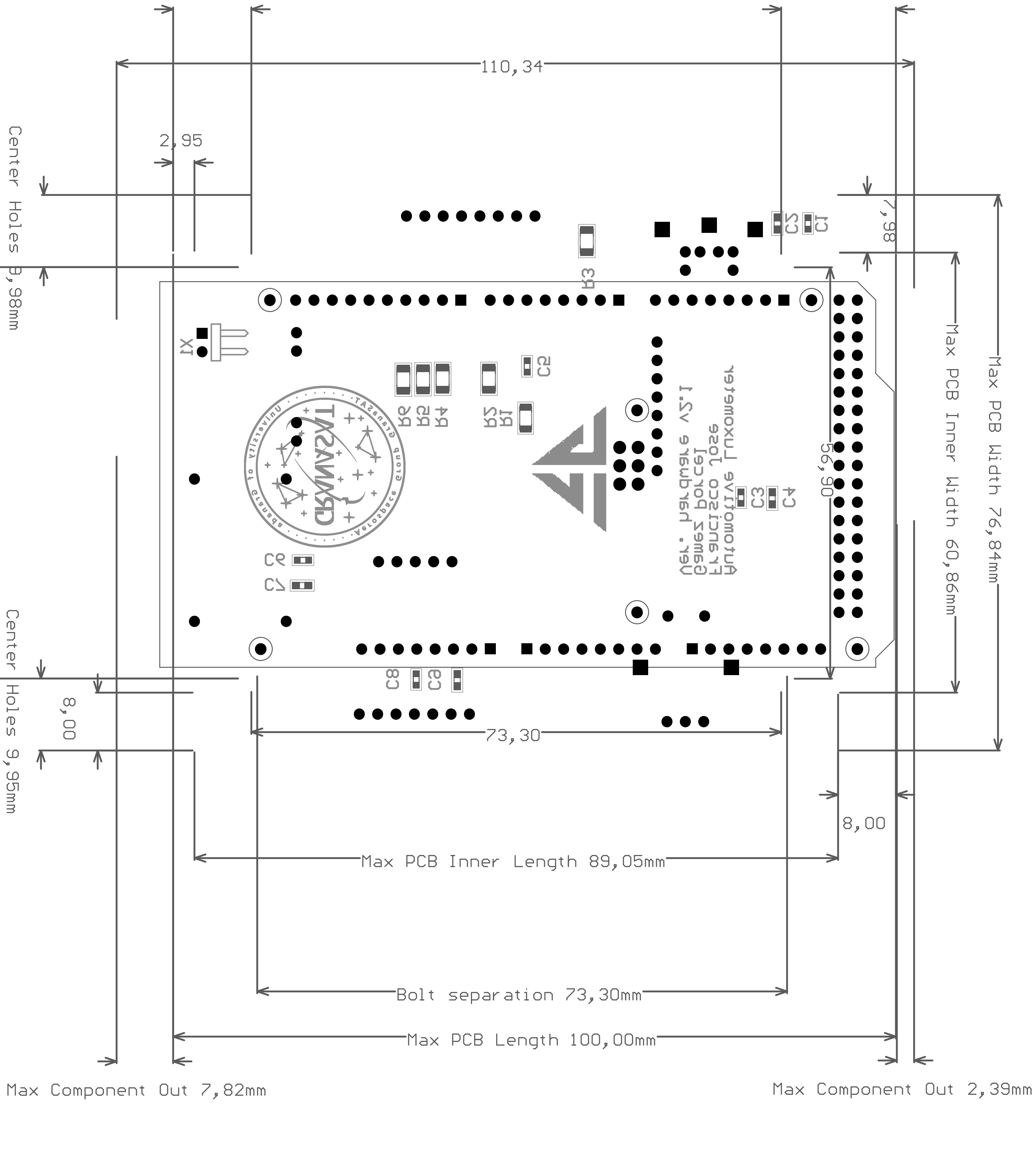
Bolt separation 73,30mm
Max PCB Length 100,00mm
Max Component Out 7,82mm
Max Component Out 2,39mm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Center Holes 9,95mm
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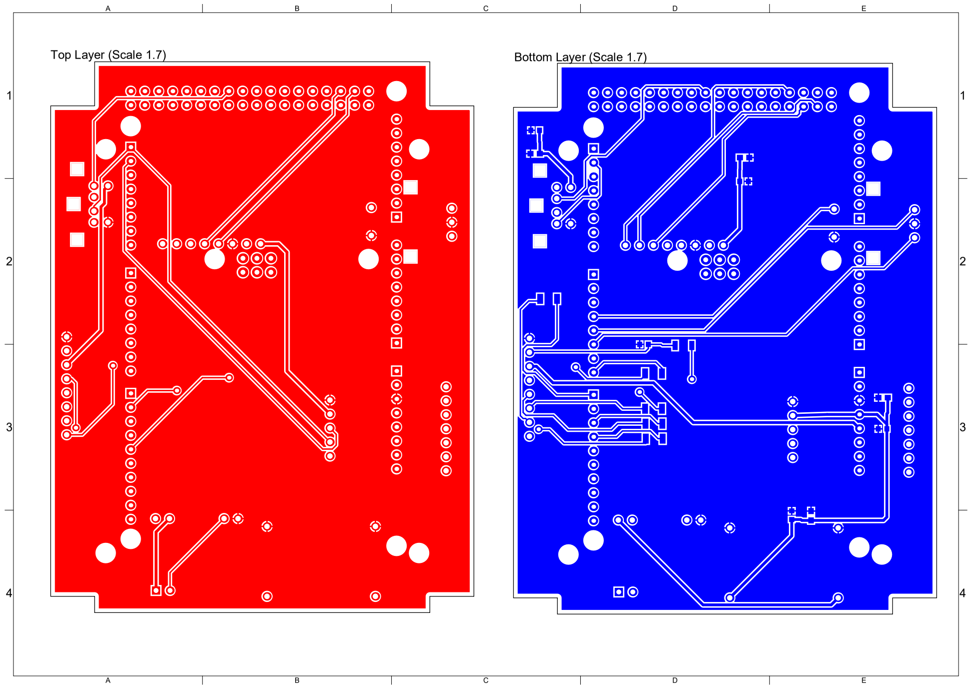
Max Component Out 2,39mm



Top Layer (Scale 1.7)
Bottom Layer (Scale 1.7)
A
B
C
D
E
1
2
3
4

Bibliography

[1] Supercars.net, 2019. Available at https://www.supercars.net/blog/1905-cadillac-osceola-coupe/ Accessed September 2019.

[2] T. MotorSport, 2019. Available at https://www.turnermotorsport.com/ Accessed September 2019.

[3] Autofacil, 2019. Available at https://www.autofacil.es/ Accessed September 2019.

[4] C. body design, 2019. Available at https://www.carbodydesign.com/gallery/2008/12/02-audi-light-design/20/ Accessed September 2019.

[5] M. Pasion, 2019. Available at https://www.motorpasion.com/ Accessed September 2019.

[6] L. Manufacturer, 2019. Available at https://www.manufacturer.lighting/info/162/ Accessed September 2019.

[7] E. N. Europe, 2019. Available at https://www.eenewseurope.com/news/samsung-integrates-wafer-level-microreflectors-multi-pixel-leds Accessed September 2019.

[8] A. Zeitung, 2019. Available at https://www.autozeitung.de/audi-lichttechnik-matrix-led-oled-laser-94841.html Accessed September 2019.

[9] A. Ryer, *Light Measurement Handbook*, 1998. http://apps.usd.edu/coglab/schieber/pdf/handbook.pdf Accessed September 2019.

[10] R. W. World, 2019. Available at https://www.rfwireless-world.com/Tutorials/OLED-basics-and-OLED-types.html Accessed September 2019.

[11] N. E. LED, 2019. Available at https://www.nighteyeled.com/ Accessed September 2019.

[12] C. Zeiss, 2019. Available at http://zeiss-campus.magnet.fsu.edu/print/lightsources/leds-print.html Accessed November 2019.

[13] Microensamble, 2019. Available at http://microensamble.com/glosario/fpc-pcb/ Accessed November 2019.