FINAL REPORT

Smart packaging for laser modules

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Abstract

Most current day packages consist of only a cardboard box and stickers with a postal address. In the case of shipment of very sensitive items, a "FRAGILE" sticker is added. In order to change this state, The Smart Packaging group under the supervision of the Monocrom company and UPC University has been established. The objective is to record several conditions which are present during shipment and to pass history of the events to the customer before opening the package. What is more, the content of the package has to be secured against shocks, ESD and humidity. The following paper shows results done in various realms such as: electronics, sensors, inner foams, outer box, materials and describes the first steps of designing process.

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1 Introduction

1.1 The Company Monocrom

Monocrom are a large laser electronics manufacturer based in Vilanova i La Geltrú, Spain, they are one of the world leaders in the industry and have approximatley only 7 other competitors globally. Monocrom develop a wide variety of laser diodes for a wide variety of industries like aerospace, defence, hair removal and opthalmology to name a few. Monocrom are most commonly known within the laser diode industry for developing a new patented manufacturing technique called clamping to eliminate the smile effect caused by conventional laser diode manufacturing methods, this increases the laser diode longevity and allows for a greater control over the emmited light.

Figure 1: Large Cylindrical Diode

Figure 2: Large Stacked Diode

1.2 The Problem

The laser electronics company Monocrom faces an issue brought upon them by the shipping companies they use to ship their products around the globe, these products are being damaged during shipping and the damage can not be identified until the product is opened by the customer. High powered laser diodes are extremely expensive and therefore also expensive to repair, currently it is difficult to claim insurance from the shipping companies once the package has been opened as there is no way of distinguishing who damaged the goods.

1.3 The Project

Laser diodes are very sensitive modules which can be easily damaged during the shipping process, therefore, it is imperative to protect the laser diodes against uncontrollable forces while shipping. This project consists of designing a smart package for some of the laser diode modules of the Monocrom company that ensures their protection against condensation, shocks, vibrations, electrostatic discharge and scratches. With the aid of indicators, sensors and data loggers the packaging should also record important information about the conditions in which the diodes are subdued during the shipment. The packaging should allow the recipient to gain access to the logged information prior to opening the package.

1.4 Current Packaging Solutions of the Company

Currently Monocrom delivers their laser diode modules in standard generic packaging which is both unsightly and unreliable for protection, the current package costs approximately 10€ per diode, in simple cardboard boxes filled with ESD protective foam, see figure 3. The smaller stacked diodes are additionally protected against electrostatic discharge, dust and moisture with a special conductive ESD vacuum bag, the larger more expensive diodes are shipped with pre-fitted lenses which must be protected from scratches with soft cloth bags similar to those used for sunglasses.

Monocrom has already developed a prototype of a plastic packaging which is used for one of their smaller laser diode modules but cannot be used to accommodate larger diodes due to its size, this packaging costs 25€ to manufacture but does not incorporate sensors or dataloggers and is not inter changeable between diodes, see figure 4. This solution is still of a dissatisfactory level but gives a foundation in which to design a new smart package, Monocrom would like a smart package solution which emphasizes the high quality and value of the diode lasers being delivered.

Figure 3: Current Packaging for the Cylindric Diode

Figure 4: Plastic Cox for the Smaller Cylindric Diode

Figure 5: Packaging for 4 Cylindrical Diodes

Figure 6: Packaging for Stacked Diodes

Figure 7: Packaging for Smaller Stacked Diodes

2 Existing Smart/Intelligent Packaging

2.1 Introduction

The first step in the project was to do research on existing smart packaging solutions and to find out if they can be applied for the laser devices.

2.2 Definition of Packaging, Intelligent Packaging and Smart Packaging

In general a packaging can be defined as a cover of an object [1]. The basic functions of a packaging are to protect a product, to give information about the content and to promote it [2]. Packaging is also used to simplify and improve the storage and transportation of products [3].

Intelligent packaging describes a packaging system with intelligent functions, for example the detection, perception, recording and communication of certain indicators [4].

The smart packaging concept is an intelligent packaging which works with integrated technologies. A smart packaging contains additional new functions and saved information can be released by a device [5]. The laser devices will be packed at this level, focussing on the protection of the modules, detection of problems during the transportation and communication of those problems to the customer.

Smart and intelligent packaging can be mostly found in the food sector, so the project group tried to apply existing solutions for food to the laser modules packaging.

2.3 Examples for existing Smart/Intelligent Packaging Solutions

2.3.1 TT Sensor Plus

This is a credit-card size time-and-temperature sensor used during the transportation of camel's milk, see figure 8. The milk is packaged in 16oz plastic bottles, which are shipped to the customer refrigerated or frozen in isolated boxes packed with dry ice.

The company Avery Dennison developed this small data logger, called TT Sensor Plus. This card contains a time/temperature logger, a flexible battery and a Near-Field Communications chip, which enables easy access to the data via smart phone, see figure 9. The sensor also reflects location, distance, shipping time, whether the content is refrigerated or frozen and the amount of dry ice used.

They placed one sensor inside the box and one outside the box to record exterior conditions.

The price per unit is about 14€ and there are more customers, which use the TT Sensor Plus [6].

Figure 8: Smart Milk Packaging

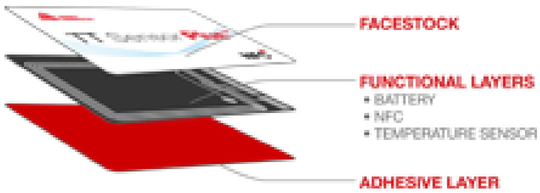


Figure 9: TT Sensor Diagram

2.3.2 The Indicator from TEMPIX

This temperature indicator uncovers whether the product (food) has been handled at too high temperatures during its shipment from the producer to the customer. It works as a guarantee that the product has been handled correctly.

When the product is alright you can see the black bar in the Tempix indicator. If the black bar disappears from the indicator, the product has been exposed to temperatures above the recommended limit at any stage of its handling. In addition, if something went wrong with the product, the barcode changes, so that it is not readable anymore, see figure 10.

The indicator is composed of an absorbent part (thermo paper label), a container cap with an activator, it runs between -30°C and 30°C and is accurate to 0.5°C intervals.

This technology is environmentally friendly [7].

Figure 10: Tempix Indicator

2.3.3 Fresh Meter Time-Temperature-Indicator TTI

The company Fresh and Easy put a Fresh Meter time-temperature-indicator (TTI) on their packages for seafood. This should ensure a high quality and safe food from store to home.

It is a technology that uses temperature-sensitive ink, which is placed in the center of the Fresh Meter label. The specialty ink is surrounded by an outer ring printed in regular ink that serves as the standard, see figure 11.

The preprinted Labels are activated after locking the package. A specialized, microwave-oven sized labeler activates the Smart Meter with ultraviolet light. Afterwards the inner circle turns bright blue and starts to sense the temperature of the product. The company is able to install about 120 labels per minute.

Consumer can now compare the inner colour with the surrounding static colours and therefore evaluate the freshness of the product [8].

Figure 11: Fresh-O-Meter Indicator

2.3.4 Insignia Intelligent Labels

The intelligent labels from Insignia Technologies are able to display food freshness after the package was opened by measuring CO_2 levels inside the packaging. When the package is closed, the food is surrounded by CO_2 and the label is yellow until the package is opened. Once the package is opened, the CO_2 streams out and the label begins to change its colour, see figures 12 and 13. The colour changes faster in higher temperatures and so the consumer can easily assess, if the food is still fresh [9].

The company uses intelligent plastics and inks for their labels. They focused on intelligent pigments, which change the colour when the CO_2 levels or the temperature alternate [10].

Figure 12: Insignia Intelligent Label

Figure 13: Insignia Intelligent Label

2.3.5 NFC Open Sense™ Tags

The company Thinfilm uses smart tags to connect their products (food, alcohol, medication, health and beauty products) to consumers and partners via smart phone, see figure 14.

The tag sensor can identify if the packaging was opened or not and during the supply chain it alerts manufacturers, suppliers and consumers about tampering.

The tags are also used to deliver information to the customer, for example product origin, reviews and promotional offers. It can even suggest how to use the product, see figure 15.

All the information is easily readable with NFC-enabled smart phones or tablets [11].

Figure 14: NFC Open Sense Tags

Figure 15: NFC Open Sense Tags

2.3.6 Saralon: Printed Electronics for Packaging

The firm Saralon produces several electronic devices by using normal printing machines, but applying various innovative inks (Saral Inks). They can print disposable circuits and absorb them into different types of packages.

The inks are printed one-over-another in order to manufacture different electronic devices. In the end the customer can interact with the electronics integrated in the package [12].

The company focuses on three areas: Electronically Secure Packages, Promotional Marketing Items and Light Emitting Packages.

In the sections Promotional Marketing Items and Light Emitting Packages the company uses their special inks for electroluminescent displays to emit light or for SMD LEDs (Surface Mounted Device Light Emitting Diodes) [13]. This is mostly done to make different products more attractive for the customer, see figure 17 [14].

The section Electronically Secure Package focuses on using the inks for printing batteries, electro chromic displays, diodes and sensors in order to reduce counterfeiting, see figure 16. For example the company promotes the SaralSecurity Label V1, which contains a printed display, battery, connector and push sensor. The display turns on, when the push sensor is pressed and the display does not work anymore, when the package has been opened, because the connector is broken then [15].

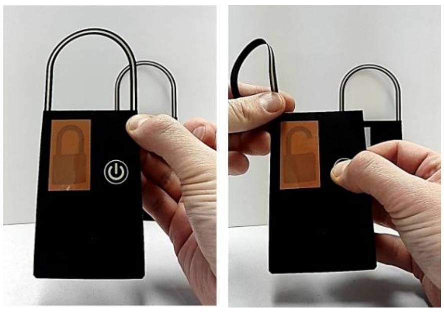


Figure 16: Saralon Printed Circuits

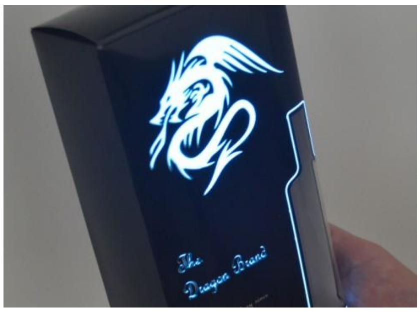


Figure 17: Saralon Printed Circuits

2.4 Evaluation of Existing Products regarding the Project

Name	Application	Functions
TT Sensor Plus	Camel's milk	Measures time, temperature, reflects location, distance, shipping time, contains NFC chip
Indicator from TEMPIX	Food	Measures temperature
Fresh Meter TTI	Food	Measures temperature
Insignia Intelligent Labels	Food	Measures CO_2 levels
NFC Open Sense™ Tags	Food, alcohol, medication, health, beauty products	Detects if package was opened or not, delivers information to customer
Saralon: Printed Electronics for Packaging	Many things	Attract costumer with luminous logos, reduce counterfeiting

Table 1: Comparison of Existing Products

Each technology is really smart and intelligent, but in the end those innovations do not cover all the required functions for the packaging of the laser modules. The Fresh Meter time-temperature-indicator and the temperature indicator from TEMPIX can only measure temperature, the Insignia Intelligent Labels can measure CO_2 levels, the TT Sensor Plus is able to measure time and temperature and contains a Near-Field Communications chip, NFC Open Sense™Tags only involve one sensor. Saralons printed electronics are simple and cost effective, but in the case of the project not suitable. All these technologies are not in a position to record and measure vibrations, shocks, electrostatic discharge or scratches. It was necessary to come up with individual ideas for the smart packaging for the laser modules.

3 Evolution of concept`s

Initially, the approach of the team was to design a "smart" package for one diode, the packaging should consist of a special system which would be able to record various conditions during a shipment, the package should be designed in such way that it would provide a second purpose or be easily recycled. One of the most important constrains of the project was our cost limitation of 25€ per unit. Many designs have been created taking influence from many different sources, these influences provided a strong foundation in which the designs were based. Many issues were encountered when designing the packaging, material of inner and outer box, microprocessor, sensors, and power supply were all factors that caused issues when designing the box, the estimation of costs revealed that it would be impossible to produce the package within given budget. After the second meeting with the company, a new direction had been established. Monocrom had provided information on the quantity of diodes that could be sent in one shipment to a customer these being anywhere from 4 to 16 diodes, this knowledge aided in designing a package with a combination of 4 diodes to be sent together ultimately increasing the budget to 100€ per package which allowed for more flexibility of the product's design. Combining the diodes together reduces the environmental impact by reducing material used, energy for transporting and by designing the package with a second use it can be used for a much longer duration before being recycled or disposed.

After researching in the field of existing smart packaging the concept of the project's packaging was sketched. In order to gather information about the conditions of the shipment special electronics will be used. The "Smart Package" consists of following parts:

- electronics with sensors and microcontroller,
- special foam, see figure 18,
- plastic outer box with labels for customer,
- outer cardboard box with labels and stickers for courier.

The next sections describe the parts of the smart package in detail. The purpose of applying those components is, that with them it is possible to get much more information which can be more accurate. This feature is essential in case of any problems which could occur during transportation. Moreover, the idea of a mobile application is presented. This app will help the customer to get information about package.

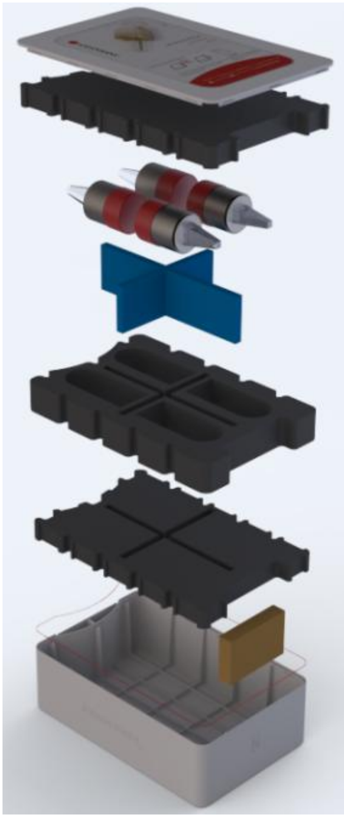


Figure 18: Explosion View of Smart Packaging

4 Microcontroller Study

4.1 Introduction

In order to measure the condition of the package during the shipping process we need to integrate sensors to our package. The sensors need to be controlled by a microcontroller. The microcontroller will be responsible for all the data collected from the sensors and also to determine the behavior of the sensors. Below we have a list of microcontrollers that we can use.

4.2 Suitable Microcontrollers

4.2.1 Arduino UNO

Operating Voltage	: 5V
Digital I/O Pins	: 14
Analog Input Pins	: 6
Flash Memory	: 32KB
Clock Speed	: 16MHz
Connectivity	: USB
Price	: 6.00€
Dimensions (L x W)	: 68.6mm x 53.4mm

Figure 19: Arduino Uno Controller

The Arduino UNO, see figure 19, provides us with a fair amount of internal flash memory and an adequate amount of processing power. It also has a built-in USB interface when it need to be connected to a computer. The only downside of the Arduino UNO is it requires a power input of 5 volts which is a lot when we take into consideration of the duration of the shipment. It is also the biggest in term of dimensions compared to the other options [16].

4.2.2 Arduino Pro Mini

Operating Voltage	: 3.35V
Digital I/O Pins	: 14
Analog Input Pins	: 6
Flash Memory	: 32KB
Clock Speed	: 8MHz
Connectivity	: -
Price	: 2.89€
Dimensions (L x W)	: 33.0mm x 17.8mm

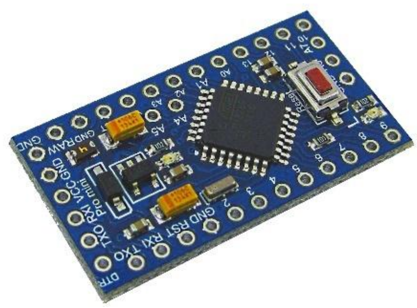


Figure 20: Arduino Mini Controller

While this Arduino Pro Mini, see figure 20, offers us with a lower processing power, it only requires 3.35 volts for the power input. Combine with low-power mode that can be configured within the program, this will result with a much lower overall power consumption which in turn will save us on the need of a high capacity battery. We may need to add a temporary USB interface to upload the program during configuration process, and add a microSD card slot to transfer files. This Arduino Pro Mini is the smallest in term of dimensions compared to other options [17].

4.2.3 Raspberry Pi Zero W

Operating Voltage : 5V

Pins : 40

Memory : MicroSD card

Clock Speed : 1GHz

Connectivity : USB, Wi-Fi & Bluetooth

Price : 23.09€

Dimensions (L x W) : 65.0mm x 30.0mm

Figure 21: Raspberry PI Zero W

Raspberry Pi Zero W, see figure 21, provides us with a very high processing power, customizable internal storage, great connectivity and also much more configurable pins. It has a built-in mini-HDMI port which we probably will never use [18]. The disadvantage of the Raspberry Pi Zero is quite the same as the Arduino UNO which is the power consumption. This is a great option if we need a high processing power and extra pins for our sensors. Keep in mind that we will need a considerably high capacity battery to power it up [19].

4.3 Conclusion regarding the Project

Characteristics	Arduino UNO	Arduino Pro Mini	Raspberry Pi Zero W
Operating voltage	5V	3.35V	5V
Total pins	20	20	40
Memory	32KB	32KB	MicroSD card
Clock speed	16MHz	8MHz	1GHz
Connectivity	USB	-	USB, Wi-Fi & Bluetooth
Price	6.00€	2.89€	23.09€
Dimensions (L x W)	68.6mm x 53.4mm	33.0mm x 17.8mm	65.0mm x 30.0mm

Table 2: Performance of suitable Microcontroller

To choose the best microprocessor, we use the following comparison table:

	Arduino UNO	Arduino Pro Mini	Raspberry Pi Zero W
PROS	-Easy to setup -Built-in USB	-More power efficient -Small size -Cheap	-Powerful processor -Connectivity
CONS	-Relatively big size -Require 5V	-Low-power processor -Need soldering -Need connection interface	-Relatively expensive -Require 5V

Table 3: Pros and Cons Microprocessors

While all three options are adequate for the tasks that we are required to do, we decided to go with the Arduino Mini Pro as it has the lowest power consumption among them. This in turn will benefit us for not having to find a high capacity battery for the electronics. It is also the smallest and the cheapest option among the three. However, we need to have an extra work to solve the connectivity issue for the Arduino Pro Mini.

5 Inner Packaging

5.1 Introduction

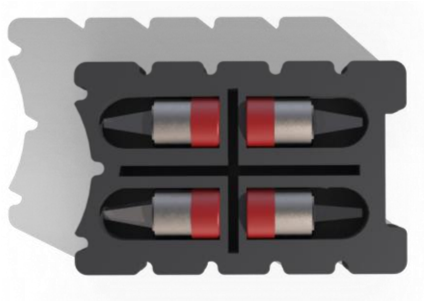


Figure 22: Foam Layout

This smart packaging has many levels of protection from the outer shipping packaging to the inner foam that carefully protects the lasers by tightly holding them in a fixed position while being shipped. This section will discuss the inner foam used within the smart package that will directly hold the laser diodes in position, this foam will be cut to the exact dimensions of the diodes to reduce shocks and vibrations, this will also protect the lens from being scratched.

5.2 Recyclability

When considering polymer foams for this or similar applications it is imperative to consider their environmental impact in both production and recyclability, the two main polymers used in ESD foams are polyethylene and polyurethane.

Polyurethane and Polyethylene *can* be disposed of in two ways, landfill and incineration, neither of these methods are desirable as they pollute the earth and create a need for more polymers to be manufactured. Both materials can also be recycled in two ways, physically recycling the material means to crush it down and form it into different polyurethane or polyethylene products or polyurethane can be chemically recycled by re-polymerisation this breaks the chemical down to a raw monomer that can be re moulded to create new products [22]. Each of these products has their own advantages and disadvantages which have been listed in the below table which applies to both polymer types except for chemical recycling for polyethylene which needs high temperature melting instead of chemical decomposition [23].

5.3 Foam Types

5.3.1 Anti- Static Foam

Anti- Static foam is a polyurethane foam that is coated with a conductive surfactant to prevent static build-up within the foam itself and will allow a static charge to be easily transferred to the inner contents of the packaging. Anti- static ESD foam is the least expensive of ESD materials as it begins to break down when exposed to environmental elements and therefore is only suitable for one time use, the foam is usually dyed with a pink colourant to make it easily identifiable, it's surface resistance is approximately $x10^9$ - $x10^{10}$ ohm's, the larger the surface the resistance the longer the duration of static dissipation will be [20].

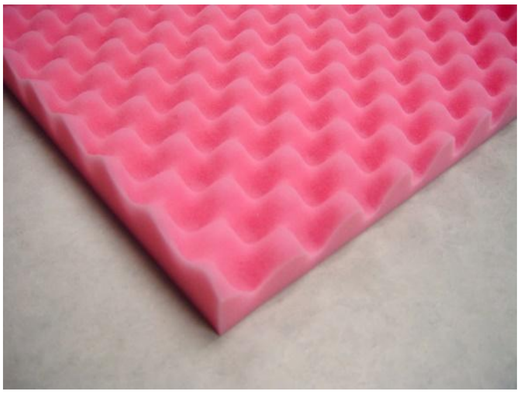


Figure 23: Anti-Static Foam

5.3.2 Conductive Foam

Conductive foam is a polyethylene foam mixed with fine carbon dust which allows it to be considered conductive and which also gives it it's dark colour, this foam is specifically designed for repeated use as it will not break down when exposed to the elements but also is the most expensive of ESD materials and has a surface resistance of approximately $x10^4$ ohm's.

Conductive foam can be used as a faraday cage when an item is completely enclosed within the material meaning there is no need for silver anti-static bags or similar shielding to protect the inner item. Conductive foam comes in two separate grades, lead-insertion and component grades, lead-insertion is used when a bare component is required to be inserted into the foam with both negative and positive leads exposed to the foam, component grade is used for transporting circuit boards hard drives or similar items.

Due to its conductive properties, any batteries should be sealed within a static conductive bag or have the contacts insulated from the foam to prevent battery drainage.

Figure 24: Conductive Foam

5.3.3 Static- Dissipative

Static-Dissipative is a polyethylene foam that can either be impregnated with carbon powder or can be coated with surfactants, the carbon version is a permanent and will not break down over time but has a higher cost than the surfactants version which also has a short lifetime but still longer than that of anti-static foam, it also has a higher carbon content than the carbon version.

Static- Dissipative is the most widely used for reusable applications and will not drain batteries as conductive foam does. It has a $x10^5$ - $x10^{10}$ ohm's surface resistance but like anti-static the inner items must be contained within a faraday cage like silver conductive bag to protect the contents [21].

Figure 25: Static Dissipative

Disposal Method	Advantages	Disadvantages
Landfill	1)simple operation 2)less input	1)difficult decomposition 2)waste of land resources
Incineration	1)recovery energy 2)relatively mature technology 3)type of polyurethane wastes with not high demand	1)produce poisonous gas 2)serious air pollution and public hazard
Recycling		
Physical	1)simple operation 2)less pollutant producing 3)high production efficiency 4)relatively less equipment investment	1)certain requirements for wastes 2)product performance, reduced the market use limited range 3)low economic benefit
Chemical	1)get the pure raw material monomer/small molecule organic matter 2)product can be used as raw material for the preparation of new products	1)high temperature or high pressure 2)the safety performance of the high demand on the equipment 3)product need purification 4)by-products difficult to control

Table 4: Comparison of Disposal Methods and Recycling of Foams

5.4 Foam Density

When choosing polymer foams for sensitive devices you must also take into consideration the density of the foam to aid in protecting the device from shocks and vibrations. There is a fine balance when choosing the correct material for ESD sensitive devices, the density must be high enough for it to contact the key points of the inner item but must also be low enough to absorb the shocks and vibrations and prevent them from being transferred to the contained device. A high-density material means the foam will be more rigid and will hold the device in a firm fixed position and will make good contact with the components negative and positive leads. Low density foams are spongier and allow slight movement of the component but absorb vibrations and shocks better than high density foams. When choosing a foam, the amount of foam that will be used and the weight of the product are also important factors that can be the defining factor that decides the correct foam for the purpose [24].

5.5 Cost for Foam

Below is a table illustrating the cost of ESD foam sheets [25].

Density	Dimensions (cm)	Thickness (cm)	Cost (Per Sheet)
Low	60.96 x 91.44	2.54	49.94€
High	60.96 x 91.44	2.54	87.71€
Memory	86.36 x 53.34	2.54	27.80€
Crosslinked	91.44 x 152.4	0.79	71.78€

Table 5: Cost for Different Foams

5.6 Conclusion of Foams

The purpose of this research into ESD foams is to distinguish the most suitable foam for the diodes needs, in this case the ESD foam will be required to fulfill two purposes each for a different type of diode, the stacked diode must be submerged in a conductive material to prevent damage from ESD. The second diode does not require protection from ESD as it is delivered with a short circuit between the positive and negative contacts but must be protected against shocks and vibrations as it weighs approximately 500 grams and is very fragile.

Therefore it is recommended that using lead insertion grade foam for the smaller stacked diodes to act as a faraday cage and protect them from ESD and that using cushion grade foam for the larger diodes is recommended to aid in protecting from shocks and vibrations.

In this case these devices have a very large cost and they cannot completely rely on the foam as complete protection against ESD, when removing the diode from the package it can easily be damaged by ESD from the handler. Monocrom ship every cylindrical laser diode with a short circuit between the positive and negative leads to eliminate any possibility of damage caused by ESD, using an ESD foam in this situation is only a secondary preventative in the case that the short circuit were to fail.

6 Outer Box Materials

Figure 26: Outer Box Material

6.1 Introduction

The products that have to be packaged are really sensitive and it is really important to choose the outer box material thinking about that. The packaging has to protect the products against shocks, vibrations and scratches and it has to be waterproof to protect the delicacy of the laser devices. In the package has to be space designed for the different sensors and the necessary technology to consider it as a smart packaging. Another constraint, as it has been commented before, is that the packaging has to cost less than 25€ per laser device including sensors and batteries. Therefore the chosen material has to be cheap and resistant taking into account how the packaging would be manufactured. With all these requirements and constraints the team has chosen plastic and cardboard as potential materials for the outer box. Plastic was chosen because of the resistant aspect and cardboard because it is very cheap and widely used for packaging in different sectors including the industrial one. In the following studies about plastics and cardboards the project group presents different types of both materials considering the resistance, the price, the manufacturing and the company's facilities to get the material. These studies indicate all the characteristics of the materials and thus the perfect material to make the ideal smart packaging for the company Monocrom can be found.

6.2 Cardboard

Cardboard is a generic term that includes all types of heavy-duty paper that can include card stock, paperboard and corrugated fiberboard. However, when we think about cardboard, the first image that pops into our head is likely corrugated fiberboard. Corrugated cardboard is made by gluing a flat sheet of paper to a corrugated sheet of paper. There are some types of corrugated cardboards depending on the boards [26].

Types of corrugated cardboards:

- **Single face board**: This type of cardboard does not have the same durability as other types of corrugated cardboard, see figure 27. However, it is cheap to produce and provides an extra layer of protection to packaged products.

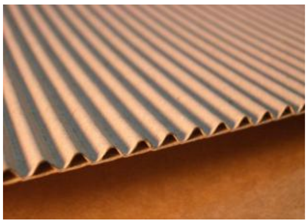


Figure 27: Single Faced Board

- **Single wall board:** This is the most common corrugated cardboard type that has five different styles of flutes, see figure 28. A flute is the inverted S-shaped arch within the type of material used to make corrugated boxes.

  - *C-Flute* is by far the most common corrugated flute because of its versatility. It is an acceptable surface to print on and strong enough for most shipping situations. It is not great at folding in the direction of the fluting, but it is still adequate for most users.

  - *B-Flute* is a little bit smaller and it is used for smaller products and boxes. It is better for folding into intricate shapes and for printing, so this is the flute usually seen for Point-Of-Purchase displays or for cardboard cutouts.

  - *E-Flute* is very thin. It is very easy to fold and excellent for printing. It is used as the primary packaging for many smaller boxes, such as a pizza box.

  - *F-Flute* is micro thin. It was designed to send less waste to landfills and it is used for specialty packaging and shoeboxes.

  - *R-Flute* is a newer type of fluting designed as an alternative to B-flute. Compared to B-Flute, R-Flute has smaller and closer fluting, which leads to an improved printing surface and less manufacturing waste [27].

Figure 28: Single Walled Board

- **Double wall board:** Resistant to breaking when stacked and is commonly used for larger industrial containers.

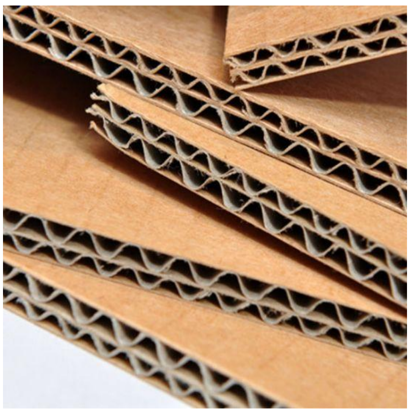


Figure 29: Double Walled Board

- **Triple Wall Board**: Strong enough to be a substitute for wooden crates [28].

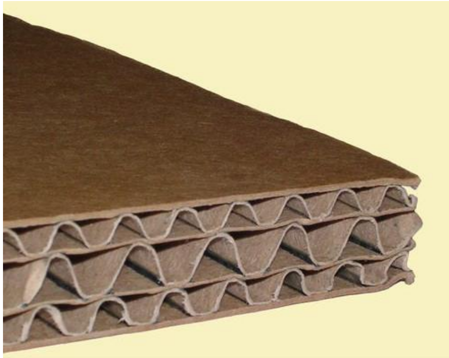


Figure 30: Triple Walled Cardboard

There is another type really used in packaging that it is not a corrugated cardboard type. It is called compact cardboard.

- **Compact cardboard**: Also called hardboard, has a matte gray color, widely used for binding (hard covers of books are made of this material). It is a cardboard of great resistance and very versatile. To work with it, it is only necessary to wet it a little bit and it will become very malleable [29].

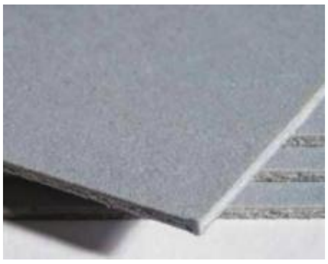


Figure 31: Compact Cardboard

Which type is the perfect one for a smart packaging? In the following table the positive and negative aspects of each cardboard type are listed, summarizing the previous information.

		Positive aspects	Negative aspects
Single face board		Cheap to produce.	Low durability.
Single wall board	**C-Flute**	Versatile and strong	Difficult to fold.
	B-Flute	Good to print.	Only used in small products.
	E-Flute	Easy to fold and for printing.	Thin, little protection.
	F-Flute	Used for boxes, easy to fold.	Really thin, poor protection.
	R-Flute	Used for boxes, easy to fold.	Really thin, poor protection.
Double wall board		Resistant to breaking.	Difficult to fold.
Triple wall board		Super strong.	Very wide, difficult to fold.
Compact cardboard		Very resistant and versatile.	Quite difficult to fold.

Table 6: Comparison of Cardboard Types

After this study about different types of cardboard it can be said that the best option for a smart packaging that needs to protect laser diodes against shocks, vibrations, scratches, condensation and which is cheap and easy to store, is the compact cardboard because it is the most resistant type and it is really used in the industrial sector. Another option could be to mix the double wall board with the single wall board in some parts of the smart packaging to increase the protection of the delicate parts [30].

6.3 Plastic Study for the Outer Box

6.3.1 Introduction

Undoubtedly all packaging materials have some sort of impact on the environment. Studies undertaken by the US Environmental Protection Agency highlight that the production of Paper bags generates 50 times more water pollutants and 70% more air pollutants than the production of plastic bags [31].

Using plastic materials for the outer box is imperative because the packaging is supposed to protect the laser devices against humidity and plastic materials allow the box to be hermetically sealed. Another reason to make the outer box from a plastic material is because this is the company’s desire.

For our kind of packaging we have to choose between most common plastics on the market: ABS, Polypropylene and Polycarbonate.

6.3.2 Acrylonitrile butadiene styrene (ABS)

Figure 32: ABS Pellets and ABS Lego Toys

ABS is tough, resilient, and easily molded. It is usually opaque, although some grades can now be transparent, and it can be given vivid colors. ABS-PVC alloys are tougher than standard ABS and are used for the casings of power tools.

ABS takes color well and has a good impact resistance and is UV resistant for outdoor application if stabilizers are added. Integral metallics are possible and ABS is hygroscopic but can be damaged by petroleum-based machining oils. It is easily molded but can be extruded, compression molded or formed to sheet that is then vacuum thermo-formed. ABS can be joined by ultrasonic or hot-plate welding, or bonded with epoxy, isocyanate or nitrile-phenolic adhesives [32].

6.3.3 Polypropylene (PP)

Figure 33: Polypropylene Samples and Glasses

Polypropylene, PP, in its pure form is flammable and degrades in sunlight but fire retardants make it slow to burn and stabilizers give it extreme stability to salt water, UV and most aqueous solutions. Standard grade PP is inexpensive, light and ductile but it has low strength but molecules can be tailored by clever catalysis, giving control of impact strength.

Polypropylene is stiffer and melts at a higher temperature (165 - 170 °C). Stiffness and strength can be improved further by reinforcing with glass, chalk or talc and is produced as sheets, moldings or it can be foamed.

6.3.4 Polycarbonate (PC)

Figure 34: Computer Casing made of PC and a PC Helmet

PC has better mechanical properties than the cheaper 'commodity' polymers. Also, it has unique characteristics of optical transparency and good toughness and rigidity, even at relatively high temperatures. PC is able to co-polymerize the molecule with other monomers, or to reinforce the PC with glass fibers to reduce shrinkage problems on cooling and to improve the mechanical performance at high temperatures.

This material is usually processed by extrusion or thermoforming, although injection molding is possible [32].

6.3.5 Comparison of Plastics

	ABS	PP	PC	Units
General properties				
Density	1.01e3-1.21e3	890-910	1.14e3-1.21e3	kg/m^3
Price	2.22-2.66	1.74-1.99	3.31-3.60	€/kg
Mechanical Properties				
Young's modulus	1.1-2.9	0.896-1.55	2-2.44	GPa
Shear modulus	0.319-1.03	0.316-0.548	0.789-0.872	GPa
Bulk modulus	3.8-4	2.5-2.6	3.7-3.9	GPa
Yield strength	18.5-51	20.7-37.2	59-70	MPa
Tensile strength	27.6-55.2	27.6-41.4	60-72.4	MPa
Compressive strength	31-86.2	25.1-55.2	69-86.9	MPa
Elongation	1.5-100	100-600	70-150	% strain
Hardness - Vickers	5.6-15.3	6.2-11.2	17.7-21.7	HV
Fracture toughness	1.19-4.29	3-4.5	2.1-4.6	MPa.m^0.5
Thermal properties				
Glass temperature	87.9-128	150-175 (melting point)	142-205	°C
Maximum service temperature	61.9-76.9	100-115	101-144	°C
Minimum service temperature	-123 - -73.2	-123 - -73.2	-123 - -73.2	°C
Thermal conductivity	0.188-0.335	0.113-0.167	0.189-0.218	W/m.°C
Specific heat capacity	1.39e3-1.92e3	1.87e3-1.96e3	1.53e3-1.63e3	J/kg.°C
Thermal expansion coefficient	84.6-234	122-180	120-137	µstrain/°C
Optical properties				
Transparency	Opaque	Translucent	Optical Quality	
Refractive index	1.53-1.54	1.48-1.5	1.54-1.59	
Eco properties				
Embodied energy, primary production	90.3-99.9	75.7-83.7	103-114	
CO2 footprint, primary production	3.64-4.03	2.96-3.27	5.74-6.35	
Recycle	✓	✓	✓	

Table 7: Technical and Economic Data about Plastics

[32]

To choose best material for our smart packaging we have to compare material aspects in the following table.

	ABS	PP	PC
PROS	- Can be conductive - Excellent impact resistance - Excellent aesthetic qualities - Easy to paint and glue - Good stiffness - Relatively low cost [33] - Strength and rigidity of the finished product - Strength to weight ratio [34] - Good machinability [33]	- Can be conductive - Relatively low cost - Has high flexural strength due to its semi-crystalline nature - Has a relatively slippery surface - Is very resistant to absorbing moisture - Has good chemical resistance over a wide range of bases and acids - Possesses good fatigue resistance - Has good impact strength [35]	- Can be conductive - Is known for its high impact resistance [39] - Excellent physical properties - Very good heat resistance - Fair chemical resistance - Moderate to high price [38] - Polycarbonate factors are resistant to sunlight, rain and snow; this enables the polycarbonate factors to last in the outdoors for many years without showing signs of fading, yellowing or discoloration [40]
CONS	- Made out of oil, so more damage to the environment - Requires a high pressure for injection - A hard impact will cause it to sharply crack - Low resistance to ultraviolet sunlight which can lead to discoloration of the surface [41] - It is soluble in many organic solvents such as ether, benzene, acetone and others [42]	- Is susceptible to UV degradation - Has poor resistance to chlorinated solvents and aromatics - Is known to be difficult to paint as it has poor bonding properties - Is highly flammable - Is susceptible to oxidation [35]	- Contains the toxic bisphenol-A (BPA) [36] - Recycling rate very low [37] - Is very susceptible to scratching [39] - Polycarbonates are highly sensitive to abrasive cleaners, alkaline cleaning products and solvents - The manufacturing process requires very high processing temperatures and is also very expensive - Polycarbonate material exhibits aromatic sensitivity or is prone to absorb odours - Although polycarbonate rates high for impact strength when compared to ABS, polyvinyl chloride (PVC) or acrylic, it is subject to stress cracking [40]

Table 8: Comparison of Different Plastics

The Monocrom's smart packaging has to protect laser diodes against condensation, shocks, vibrations, scratches and electrostatic discharge. Each of the three materials have their own unique properties but the best choice is ABS because the final product must be white because white is the company's corporate color and ABS can be pure white, it has an excellent impact resistance but it's not a subject to stress cracking, has excellent aesthetic qualities and has a good stiffness and that helps us to hold our electronic devices on the walls.

6.3.6 Conductive Plastics

Conductive plastics were considered as one of the initial designs was to incorporate individual cylindrical plastic containers for each diode, these would make contact with the diodes leads to create a short circuit to aid in eliminating any damage from ESD.

Material resistance is classified as insulating, dissipating, or conducting. Electrostatic discharge (ESD) is the transfer of accumulated electric charge from one object to another and this transfer can cause damage to the small electronic transistors within the diode. An example of ESD form is the human body becoming charged then discharging to another object or person. An ESD - protective material must protect from ESD originating externally and provide a discharge path for existing charge on the object being protected [43].

Materials for protection and prevention of Electro Static Discharge (ESD) can be categorized into three distinct groups: Anti-Static, Static Dissipative and Conductive.

Anti-Static has resistivity between 10^9 and 10^{12} ohms per square. It may be surface resistive, surface-coated or filled throughout.

Static Dissipative has resistivity between 10^6 and 10^9 ohms per square and low or no initial charges, prevents discharge from human contact. It may be either surface-coated or filled throughout.

Conductive has resistivity between 10^3 and 10^6 ohms per square and has no initial charges, provides path to bleed off. Usually carbon-particle or carbon-fiber filled throughout [44].

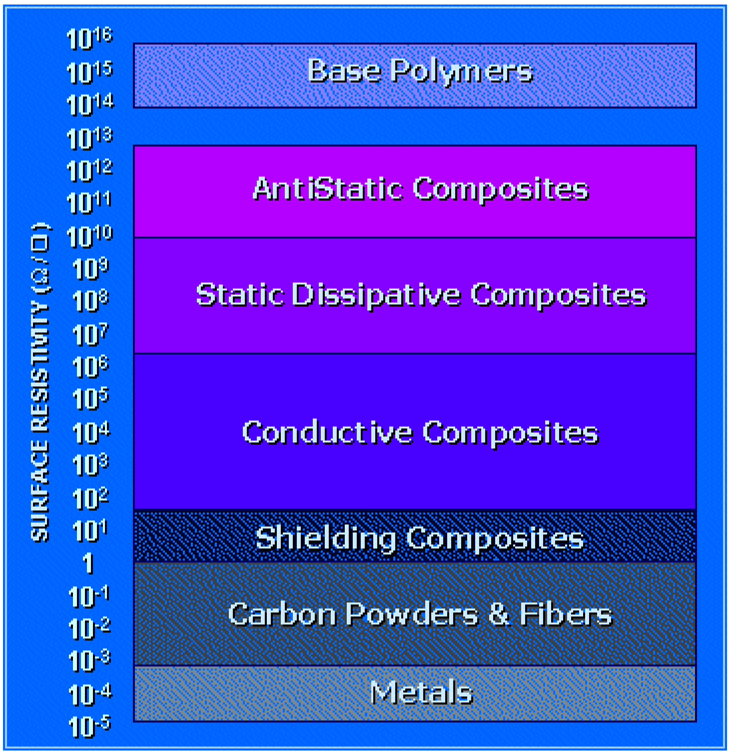


Figure 35: Conductive Polymer Table

As most plastics are normally insulators, the most common way to achieve this is to add some form of carbon to the material. Here are summaries of the different carbon forms.

	Description	Pros	Cons
Carbon Powder	This form of carbon is very fine, light, and by itself, difficult to handle.	– Relatively inexpensive – Lower conductivity is easier to control – best suited to higher resistivity ranges – Does not restrict flow much	–Dirty, powder in sufficient concentration to provide protection sloughs with the associated risk of contamination –Reduced mechanical strength – powder is a filler, not a reinforcement – The higher the powder content (increased conductivity), the more loss of strength –Makes material black and limits the ability to offer other colors
Carbon Fiber	A reinforcing element, carbon fiber is chopped to short lengths and blended into the base material.	– Increases material strength and stiffness (although stiffness may not be preferred for some applications) – Relatively clean – Improved wear resistance – carbon fiber reinforced materials have good wear properties because of their inherent lubricity, increased stiffness (less hysteresis heat buildup), and thermal conductivity – High conductivity – low loading gives good conductivity	– More expensive than powderGreater conductivity is not well suited to high resistivity applications – Makes material black and limits the ability to offer in other colors – Risk of clumping when molding product with small features creating non-uniform electrical properties
Carbon Nanotubes	Very small diameter tubes with very high aspect ratio (length to diameter), these are a relatively new option for conductive plastics.	– Improved control of conductivity compared to regular carbon fiber – Relatively clean – High conductivity	– Very expensive – Limited availability – Limited information

Table 9: Comparison of Conductive Plastics

[43]

Also, metal powders, metal particles such as Nickel, Copper, Graphite, Silver and more, aluminum flakes, or migratory and permanent antistatic polymers can be used like fillers or reinforcements. Unlike carbon powder, these additives are more spherical in shape and have low surface areas and high specific gravities. Migratory systems tend to bloom to the surface and attract moisture to the part. These are nonpermanent and, after cleaning a part, require time to regenerate antistatic properties [45].

Mechanical properties for conductive, anti-static or static dissipative plastic materials are similar to most unfilled thermoplastics which are electrically insulating, according to this site: http://web.rtpcompany.com/info/data/esd/index.htm

7 The Proposal Sketches and first Ideas for the Design

7.1 Proposal 1

The ideas at the beginning were to make a plastic box for one diode or to use a cardboard box with a plastic protection for four laser devices but some issues appeared with these ideas.

The concept of the plastic box for one diode, see figure 36, was not good because the electronics would be too expensive for a box with only one diode (the budget is only 25€ per diode).

Figure 36: Plastic Box for one Laser Device

To close the package hermetically Monocrom's employees would have to glue the lid on the box. The electronics from this concept were supposed to work with a micro SD slot, so that the costumer would have to cut the semicircle to find a micro SD slot. After fetching the data, if the package was properly delivered, the customer would cut the rest of the lid following this guidance channel, see figure 37:

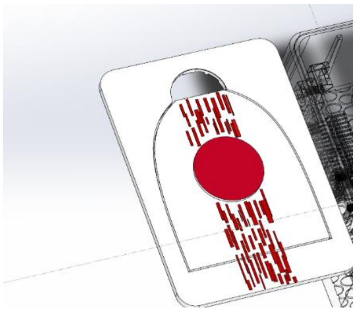


Figure 37: Box Open Security Seal

This design was disregarded as it only incorporated one laser at a time and was also to weak to be used, it also did not incorporate a security seal to avoid the package being tampered with.

7.2 Proposal 2

The next concept was to make a cardboard box and a plastic protection for the laser diodes:

With this design it is difficult to open the package because it closes by the side, sliding the lid, see figure 38.

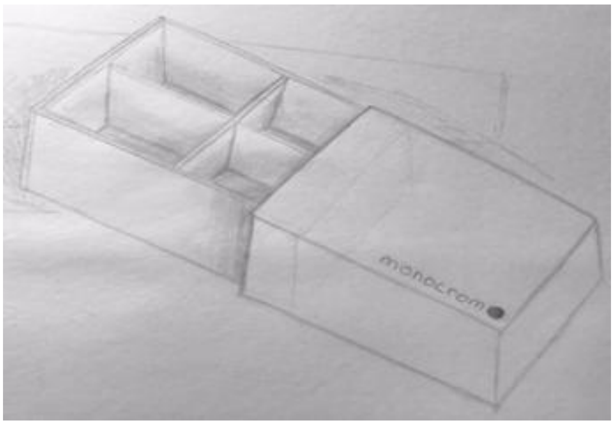


Figure 38: Initial Sketch 1

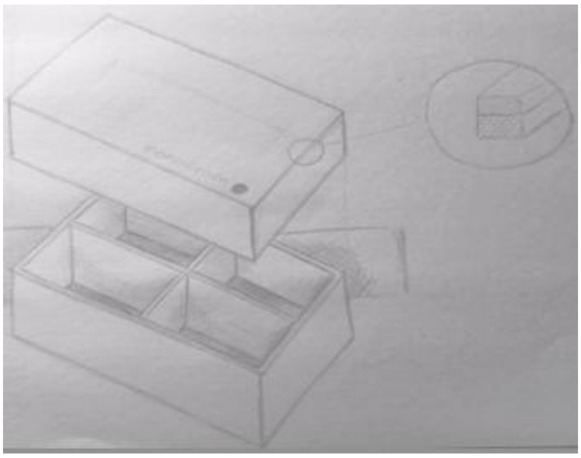


Figure 39: Initial Sketch 2

This design allows reducing the price because it is really basic but it complies with the expectations to protect the product, see figure 39.

This design is made completely of cardboard and therefore will not be able to withstand any significant amount of water, it is also very difficult to control humidity and temperature with this design and was therefore disregarded.

7.3 Proposal 3

Figure 40: Cylinder Design

The biggest problem with this concept was a bad design for the plastic assembly (the top part will remain stuck into the mould) and the company was not agreeing with this concept, see figure 40. After these two concepts and midterm defense, Monocrom expressed that a clean look is necessary.

This design is by far the most effective at protecting the diodes as it protects each diode individually, the reason for not using this design is that it has a very high cost to manufacture and also will occupy a large area of Monocrom's storage facility before being shipped.

7.4 Proposal 4

Following Monocrom's wish to design a solution with a clean look, the next concept was proposed:

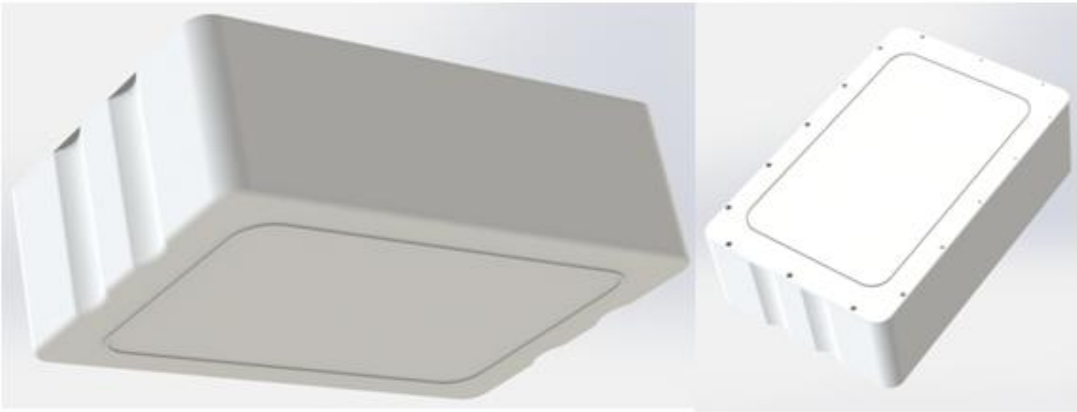


Figure 41: Plastic Box with Screws

This concept failed because it contains too many screws and, in the same time, this is a bad design with too thick ribs, with screw holes in the wall without a rib between them, which will leave sink marks, see figures 41 and 42.

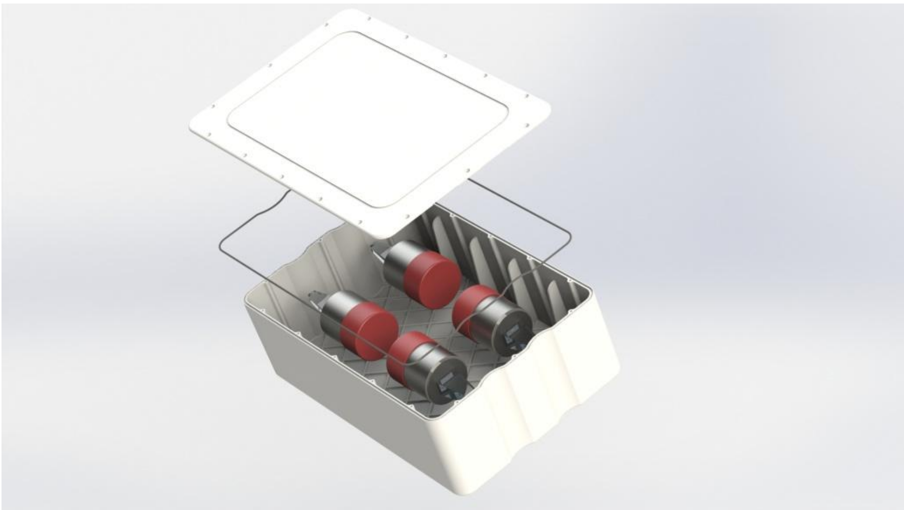


Figure 42: Explosion View of the Plastic Box with Screws

This final design is very close to the chosen design but was disregarded due to the large number of screws required to keep the box sealed, the custom O-ring would also make the design too expensive and was therefore altered slightly to get out final design.

8 Final Solution

8.1 Introduction

In this part the project team wants to show the final solutions for the problem. It is important to mention here that we decided to present two possible solutions for the design, how the package will operate technically and the final solution for the electronics part.

Regarding the design the following two concepts have to be distinguished: The first design solution is for 4 laser devices and the electronics in a big plastic box. The second design solution is for 4 existing plastic boxes, which contain one laser device each, which are put into a big cardboard box together with the electronics.

8.2 The final Design for 4 Laser Devices in a Plastic Box

8.2.1 Explanation of the Solution

Since the previous design was basically okay, it was the starting point for the final design, where the elements for the packaging (the gap from the lid and the leg from the bottom), the size and shape were kept, but the locking system was changed, see figure 43. The new locking system consists of plastic legs from the lid which will hold the lid tightly with the box and a breakable part which is a physical security system.

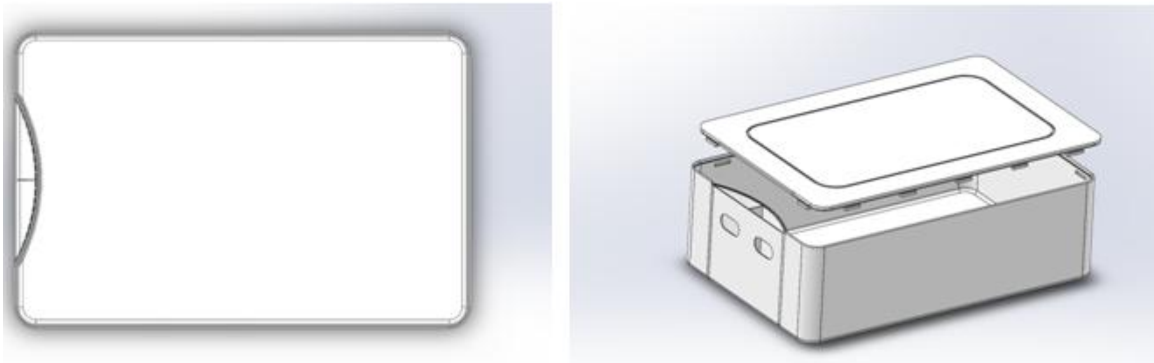


Figure 43: Final Design of the Plastic Box

The breakable part (the physical security system) is made with the main box and the customer will have to break that part to open the box. The wall between the face and the semicircle is to prevent accidentally breaking it by pressing the part. The Decision to design this security system was made because the bottom legs, which will be broken, will leave some marks and as they are on the bottom, they will not scratch the customer, see figure 44.

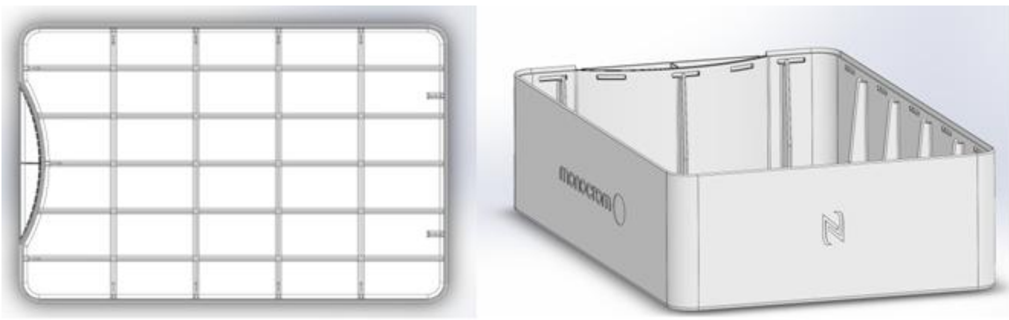


Figure 44: Final Design of the Plastic Box

The final box will have 3mm walls thickness, 2.25mm ribs thickness and 6.75 height and fillet between rib and wall has 1.13mm radius, these values are the right values which prevent it against sink marks. It has a 1mm hole for gasket and the rib from the lid has 0.7mm and is angled with 10^{o} to press the gasket easily to make the box hermetically sealed. Also the lid has ribs which will sit on the reinforcing box ribs to make the lid stiffer and protect against breaking, see figure 45.

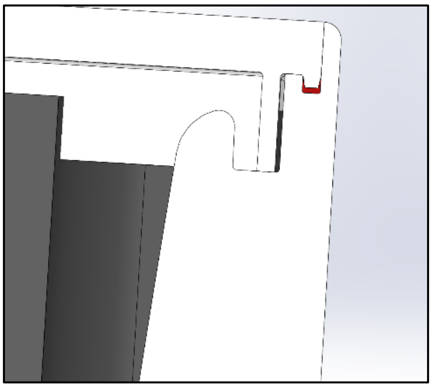


Figure 45: Section View

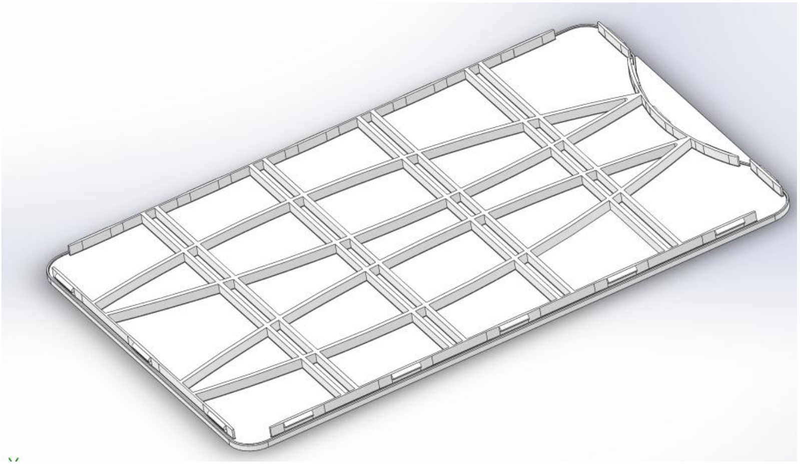


Figure 46: The Lid

The lid, see figure 46, has to be properly reinforced because it will carry the weight from another box or another two boxes, when they are stacked, and the round ribs are made in this shape to permit the walls to flex, otherwise the legs would break and a stress test with a force, which simulate 6kg on the top of the box, shows that the maximum displacement will be 0.29mm (see Appendix 1. Lid Test).

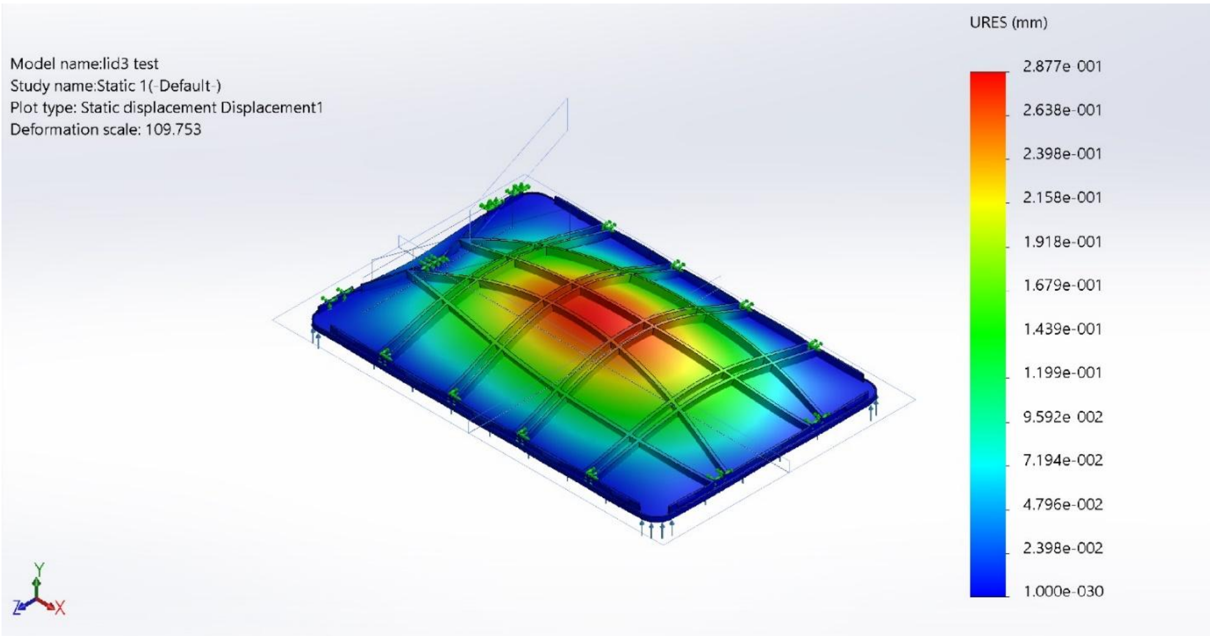
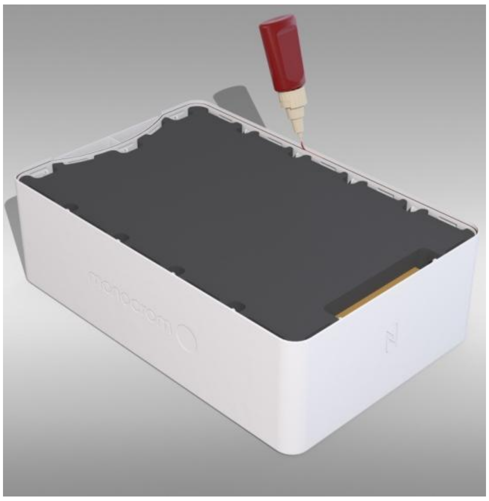


Figure 47: Stress Test Simulation for the Lid

Likewise the box includes a space for the electronics box and on the bottom and the top a low density foam will be installed to work like shock absorbers. The middle foam is a high density foam to hold the laser diodes tightly. In these foams are some channels are made to insert HDPS walls in order to separate the laser diodes and to increase the protection, see figure 48.

Figure 48: Final Design with the Contents



To make the box hermetically sealed a gasket maker is used because it is easy to use, cheap and has the same properties as an injected gasket.

Figure 49: Gasket Maker

When a customer will receive this package he will see figure 50:

Figure 50: Package was received

The customer will receive a cardboard shipping box that they will open and find inside the smart packaging box that they will open with instructions given on the outer box, see figure 51:

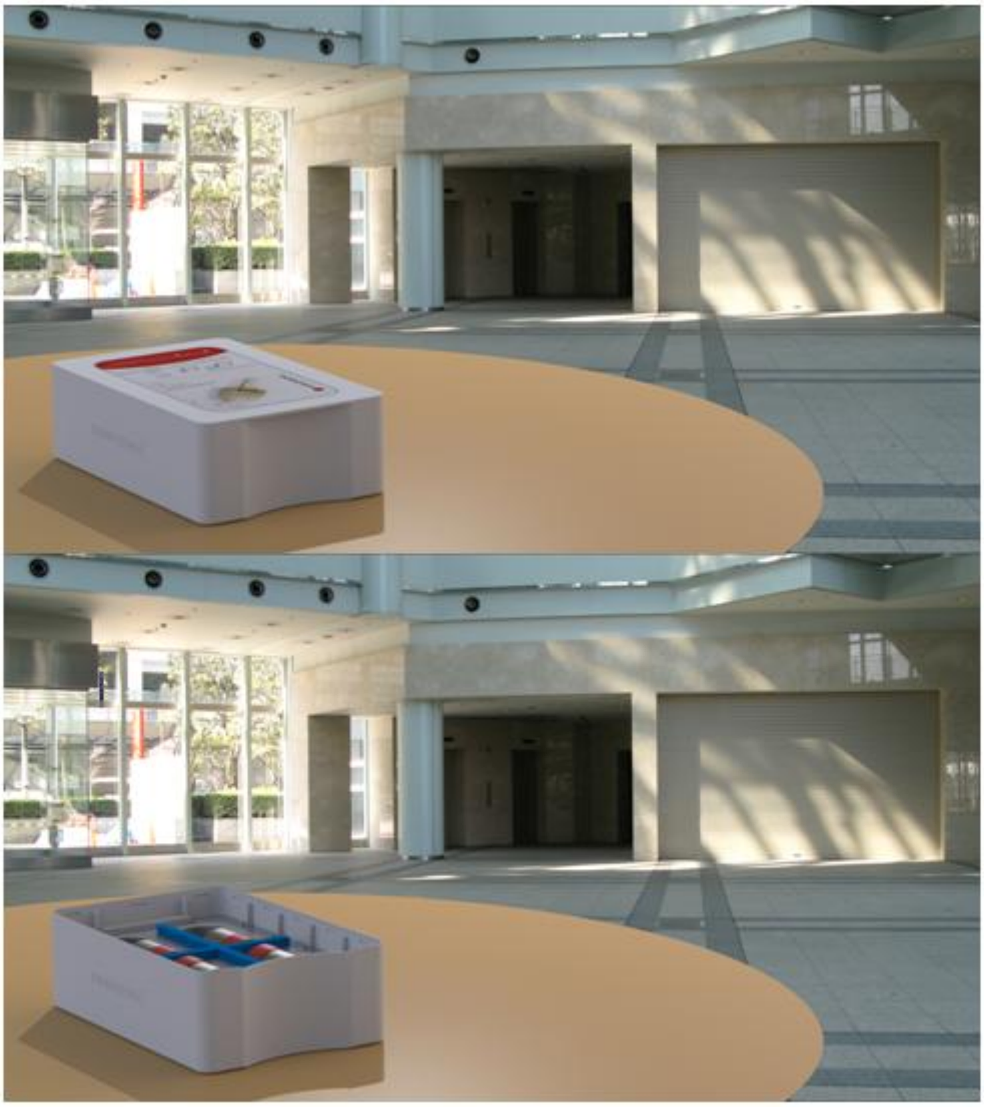


Figure 51: Box after the Opening

The aesthetic part consists in the company logo and NFC logo which are embossed, a sticker which will show how to open the box on the removable part and a sticker with what is inside the box, details about product and how to establish a connection between the box and a mobile phone and this is the final result:

In the "Appendix 2. Drawings" the drawings for this solution can be found.

Figure 52: Final Solution

8.2.2 Steps to assemble the Box

The assembly will begin with an empty box to a hermetically sealed box following these steps:

1) The box has to be on a flat surface.

Figure 53: Box

2) Next step is to place the low density foam in the bottom of the box.

Figure 54: Box with low density foam

3) Followed by placing a high density foam

Figure 55: High Density Foam

4) and HDPS/E walls to separate the compartments.

Figure 56: HDPS/E Walls

5) The next step is to insert into the cavities the laser diodes

Figure 57: Box with Laser Devices

6) and the box with sensors, the microprocessor, NFC-and Bluetooth module.

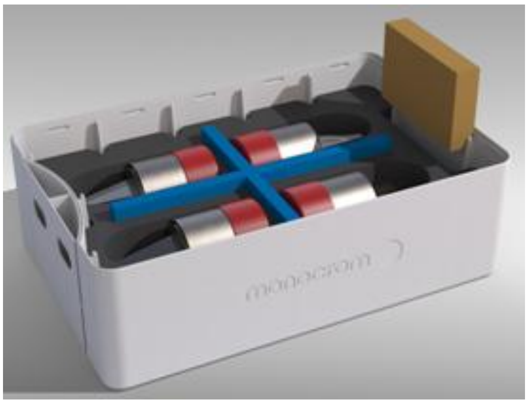


Figure 58: Electronics

7) The last part which has to be inside the box is another part of low density foam.

Figure 59: Low Density Foam on Top

8) The next step is to apply the gasket maker.

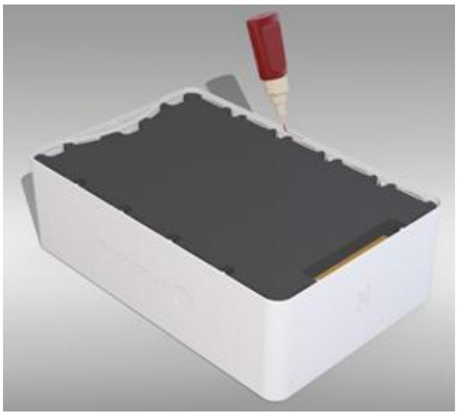


Figure 60: Gasket Maker

9) The last step is to close the box with the lid and to leave it at least 30 minutes to dry.

Figure 61: Closed Box

8.3 Final Solution for the Existing Small Plastic Boxes

The "Smart Packaging" project can also work in a different way. Although making a new plastic box which can contain 4 diodes, Monocrom's present packaging, the already existing smaller plastic boxes can be used. They can hold only one diode per box and moreover there is no place for the electronics inside. In order to solve this problem the following option can be proposed. The package will consist of following parts: a big cardboard box with appropriate labels and stickers, the existing smaller plastic boxes with foam inside and a laser device in each box, a cardboard box with electronics, see figure 62. The "smaller boxes" containing the diodes will be placed in the big cardboard box and the box with electronics will be put next to them.

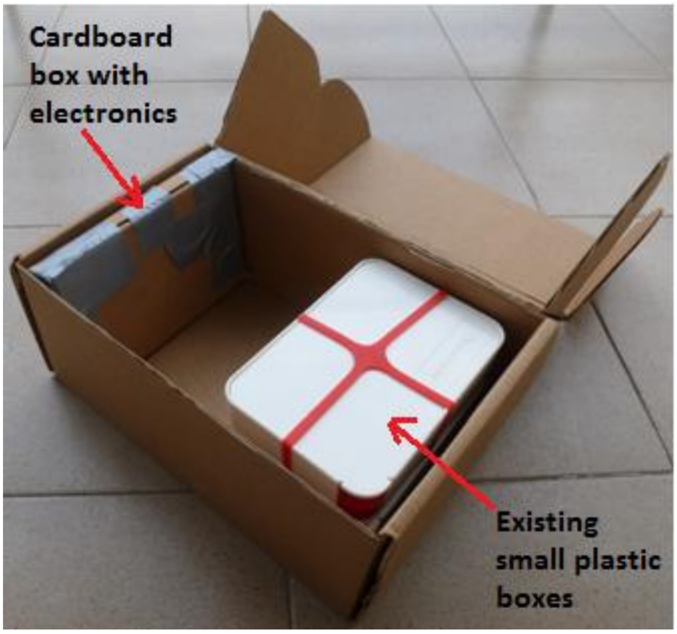


Figure 62: Big Cardboard Box with the small existing plastic Boxes

After receiving the package the customer has to scan the QR-code in order to download the mobile application and the NFC label which will initiate the connection to send the data.

8.4 Smart Package Technical Operation

The current smart packaging solution will operate with use of an accelerometer and temperature and humidity sensor connected to an Arduino pro mini microprocessor, the sensors are stored inside the smart packaging and will constantly monitor temperature, humidity, orientation, vibrations and shocks. Data is collected by the sensors and processed via the Arduino and then stored as a text file on an SD card via an SD card module.

When the package has been delivered the customer will be instructed to enable NFC and connect to the internet via Wi-Fi or cellular signal on a smart phone. The customer will then place the smart phone against the NFC symbol on the outer package, doing this will establish a Bluetooth connection between the smart phone and the Bluetooth module installed within the smart package. A text file created by the Arduino will be extracted from the SD card and sent to the smart phone via Bluetooth as well as opening Monocrom's webpage in which the text file can be uploaded and sent back to Monocrom.

8.5 Final Solution for Electronics

8.5.1 Introduction

This section presents the research made in order to find out the proper sensors that can be applied in "Smart Packaging". In this project, sensors like: accelerometer, thermometer, humidity are needed. It is important to mention here, that the Arduino Pro Mini was chosen as can be seen in the study section of microcontrollers because of the advantages that it has over the rest.

All the electronics will be assembled in a small cardboard box, which is put inside the smart package next to the laser devices.

8.5.2 The Accelerometer

Among the parameters that need to be measured are shocks and vibrations, which can be converted into accelerations. For that reason, an accelerometer is used as it can measure gravitational accelerations that can be used to calculate shocks and vibrations experienced by the package. These are the parameters that the diode can withstand up to:

Shocks: 50g

Vibrations:

- Frequency : 50Hz
- Amplitude : 3mm
- Duration : 2s

To convert the parameters for the vibration into acceleration in g, this equation is used:

$$a = \frac{-(2\pi f)^2 \cdot x}{9.81}$$

Where *f* is the frequency in Hertz and *x* is the amplitude in meters.

As a result, we get around 30g of acceleration at its peak. This is important to determine the type of accelerometer to use in this project. The team uses the ADXL377 High-g Triple Axis accelerometer as it can measure up to 200g and it is compatible with the chosen Arduino [46].

Specifications:

- Input voltage : 3.3V or 5V
- Range : ± 200g
- Axis : X, Y and Z
- Dimensions : 19mm x 19mm x 3.14mm

Figure 63: Accelerometer

Pins and Connections:

ADXL377	Arduino
3V	VCC
GND	GND
X	A0
Y	A1
Z	A2

Table 10: Pins and Connections ADXL377

8.5.3 Temperature and Humidity Sensor

To measure temperature and humidity of the package throughout the shipment, we need to use a sensor that is capable to measure at least up to the level that the diode can withstand which is 60°C of temperature and 80% of humidity. We choose to use the DHT22 temperature and humidity sensor as it is compatible with the Arduino and it is in our measuring range [47].

Specifications:

- Input voltage : 3V – 5.5V
- Temperature range : -40°C – 80°C
- Humidity range : 0 – 100% RH
- Dimensions : 28.2mm x 13.1mm x 10mm

Figure 64: Temperature and Humidity Sensor

Pins and Connections:

DHT22	Arduino
+	VCC
-	GND
out	8

Table 11: Pins and Connection DHT22

8.5.4 Evaluation of electronic sensors

The main advantages of the above sensors are accuracy of measurements and ability to connect to a microcontroller, like the Arduino, which can process data. It can gather information about every moment of shipping. Additionally, the first sensor is combined from two. The disadvantages are prices and complexity of assembling and programming. The sensors should be joined to the special board and then to the microcontroller which needs power and a NFC/Bluetooth module. Those sensors can be combined with the Arduino microcontroller.

	Advantages	Disadvantages
Temperature-humidity sensor	• Combines thermometer and humidity sensor • Low power consumption • Long term stability • Price: 4.82€	• Complexity of assembling and programming
Triple Axis Accelerometer Breakout	• Compact • Low power consumption • Measures up to ±200 g • Free-falling detection	• Complexity of assembling and programming • Price (huge in comparison to other components

Table 12: Evaluation of Electronic Sensors

8.5.5 The Micro SD Module

A micro SD card module is needed because we record the data throughout the shipment so that Monocrom will be able to see the evolution of the parameters. We use a common SPI Micro SD card module that works for Arduino [48].

Specifications:

- Input voltage: 4.5V – 5.5V
- Dimensions: 24mm x 42mm x 3.2mm

Figure 65: Micro SD Module

Pins and Connections:

Micro SD module	Arduino
VCC	VCC
GND	GND
MOSI	11
MISO	12
SCK	13
CS	4

Table 13: Pins and Connections of Micro SD Module

Modifications:

To use this module with 3.3V of input voltage, some modifications are required to the board. On the module, there is a Low Drop-Out (LDO) regulator with input voltage of between 4.5V and 5.5V, and an output voltage of 3.3V. A bypass is needed so that the voltage provided by the Arduino, which is 3.3V, does not enter the input pin of the voltage regulator and goes directly to the output pin of the regulator as shown in figure 66.

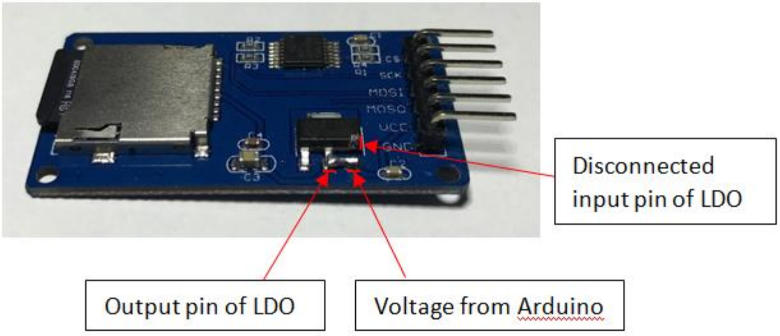


Figure 66: Modifications

8.5.6 The Bluetooth Module

A Bluetooth module is required to transfer the recorded data on the micro SD to a mobile phone. We use the SH-HC-08 Bluetooth 4.0 LE Transceiver module as it is compatible with the Arduino, Android and iOS [49].

Specifications:

- Input voltage : 3.6V – 6V
- Working range : 10m
- Dimensions : 35.7mm x 15.2mm x 4.3mm

Figure 67: Bluetooth Module

Pins and Connections:

SH-HC-08	Arduino
GND	GND
TXD	RXD
RXD	TXD

Table 14: Pins and Connections Bluetooth Module

Modifications:

Like the micro SD module, the working voltage of the module is also rated at 3.3V but the input voltage is between 3.6V and 6V. Thus, we need to redirect to voltage from the Arduino to the Bluetooth module itself instead of going through the voltage regulator as shown in figure 68.

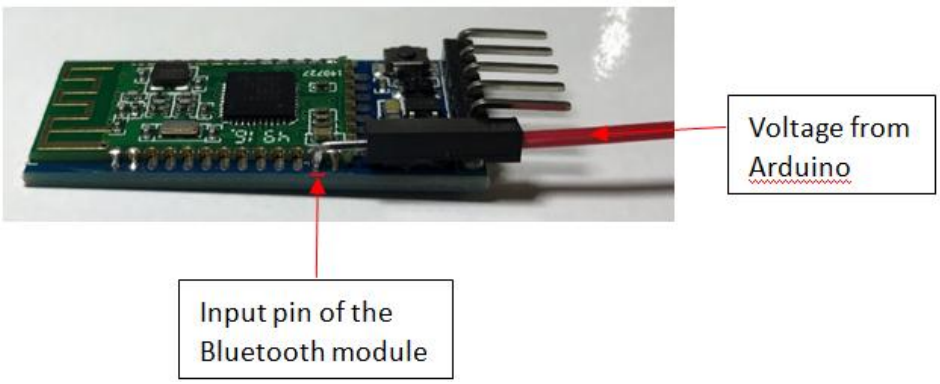


Figure 68: Modifications

8.5.7 NFC

The implementation of NFC to this project is to facilitate the pairing process between the package and an Android mobile phone as it will reduce a few steps. This also should improve the security of the data in the package as the data will only be transferred to the mobile phone when they are placed close to each other [50].

Specifications:

- Voltage input : 3.3V or 5V
- Chip : PN532
- Range : 3cm
- Dimensions : 63mm x 54mm x 4mm

Figure 69: NFC Module

Pins and Connections:

NFC	Arduino
VCC	3.3V
GND	GND
SDA	A4
SCL	A5

Table 15: Pins and Connections NFC

8.5.8 FTDI USB to Serial adapter

To upload the Arduino sketch file to the Arduino, a USB to serial adapter is required as it does not have any built-in USB connection. We use a standard FTDI USB to Serial/UART TTL adapter to connect the Arduino to a computer [51].

Specifications:

- Voltage output: 3.3V or 5V
- Chip: CP2102
- Dimensions: 48mm x 16mm x 4.5mm

Figure 70: Adapter

Pins and Connections:

FTDI USB to Serial	Arduino
3V3	VCC
GND	GND
TXD	RXD
RXD	TXD

Table 16: Pins and Connections FTDI USB to Serial

8.5.9 Arduino IDE

Arduino IDE is an open source software, used for writing Arduino sketches and uploading it to the board. It is compatible with Windows, macOS and Linux [52].

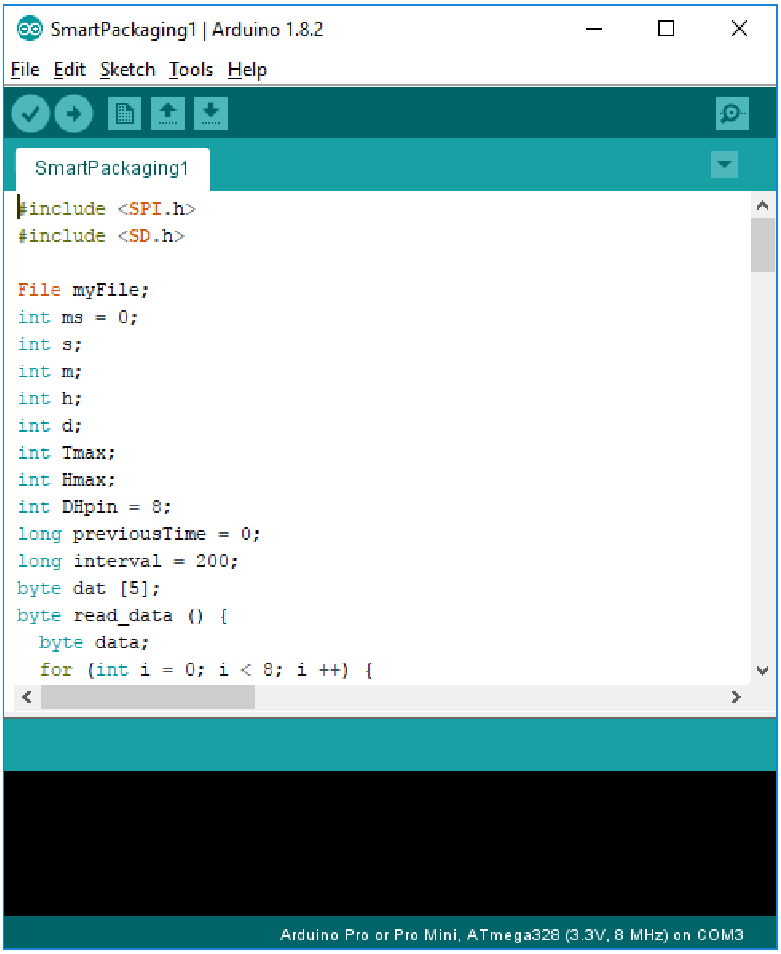


Figure 71: Arduino IDE

Before we can upload the sketch, some settings need to be made to the Arduino IDE.

1) Select the right Arduino board.

Go to **Tools** > **Board**: > and select **Arduino Pro or Pro Mini** as shown in the figure 72.

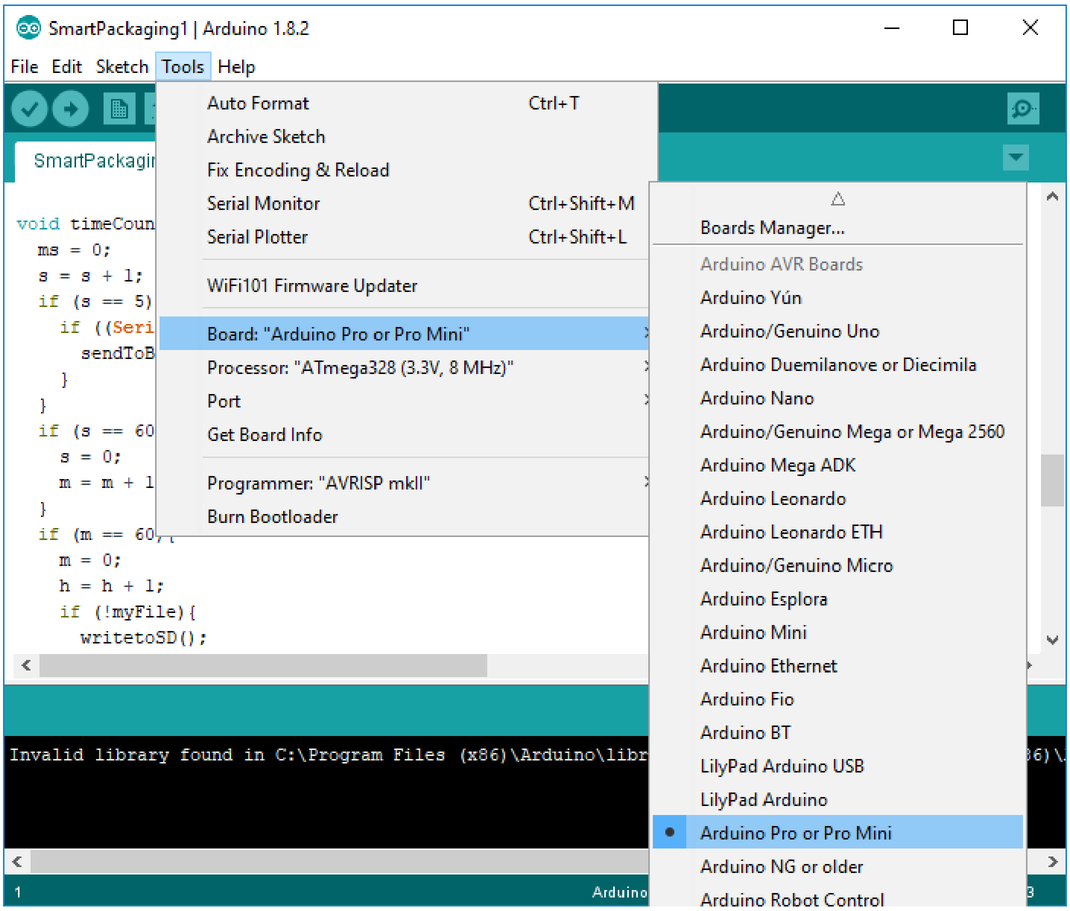


Figure 72: Selection of Arduino Board

2) Select the right processor.

Go to **Tools** > **Processor**: > and select **ATmega328 (3.3V, 8MHz)** as shown in figure 73.

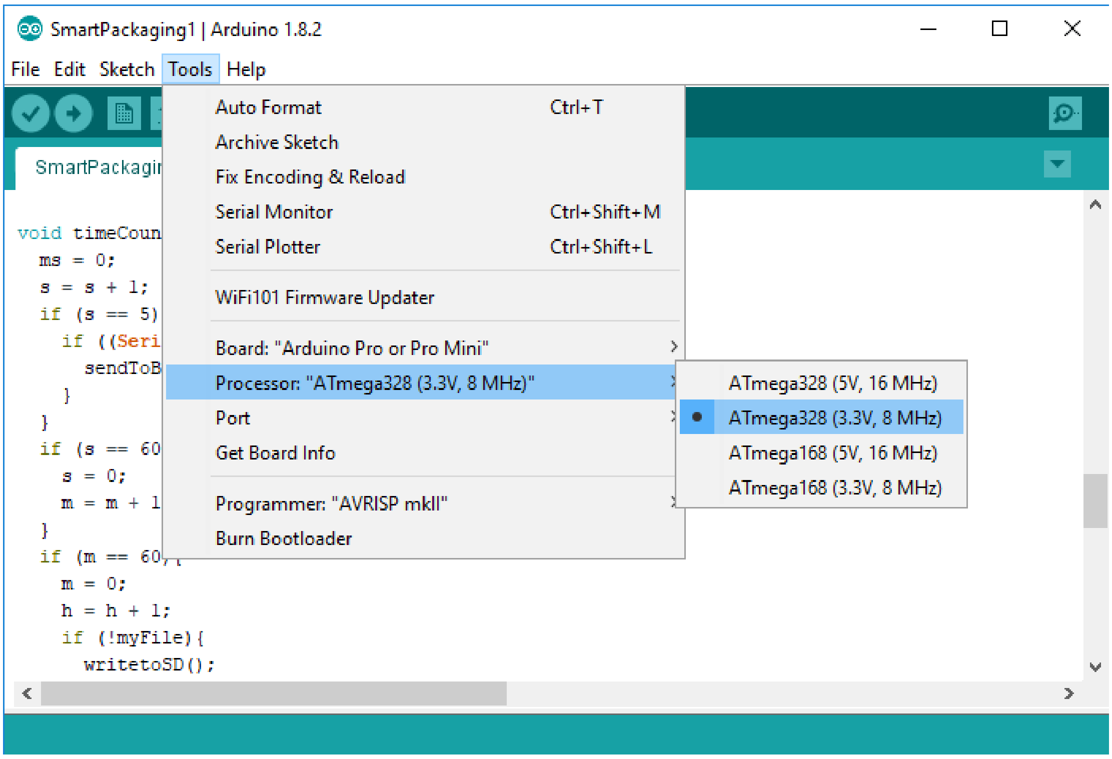


Figure 73: Selection of the Proccessor

3) Select the right port.

Go to **Tools** > **Port** > and select the right port e.g. **COM5** as shown in figure 74.

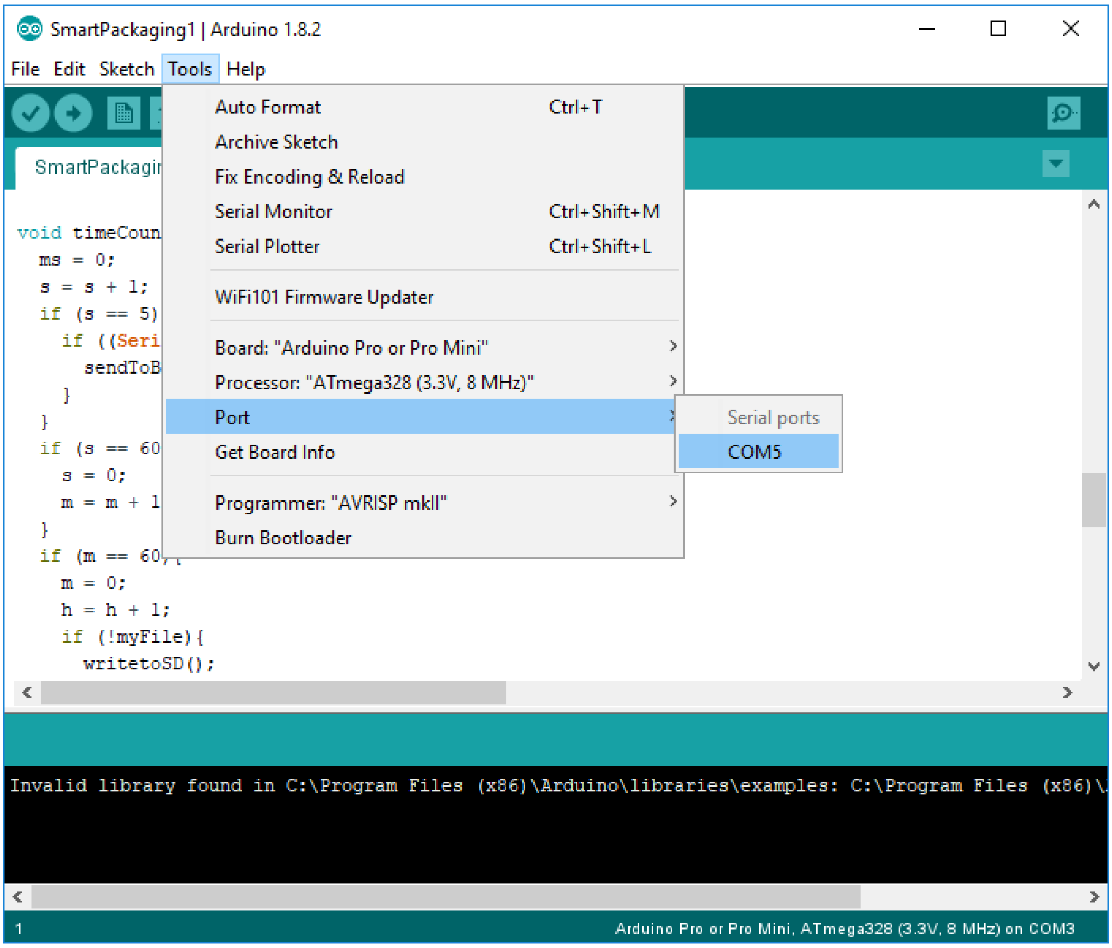


Figure 74: Selection of the Port

4) How to upload the code.

Once the Arduino code is loaded and the settings are done, upload the code to the board by pressing the right-arrow button at the top-left of the Arduino IDE window.

The complete Arduino sketch can be found in the appendix of the report (see Appendix 3. Arduino Code).

9 Communication between Customers and Monocrom

9.1 The Communication

One of the matters which should be considered is the way of sustaining the contact with the customer. With the aid of this contact, it will be possible to receive all necessary data of the shipping conditions. The "Smart Package" is not equipped with any Internet module, which could send data straight to the manufacturer. In this case, it is necessary to establish a way of communication in order to receive important data from the customer.

All the data which will be gathered by the sensors and processed further by the microprocessor will be kept in storage in an executed text file. As it is described in previous sections, the NFC and Bluetooth module will be used in order to transfer data to the mobile phone of the customer. On the mobile phone an application will be working. Due to the application, sending data back to the company Monocrom can be done with a little effort from the customer.

On the smart package will be a storyboard, see figure 75, with short explanations which introduces the customer to the process of sending the data.

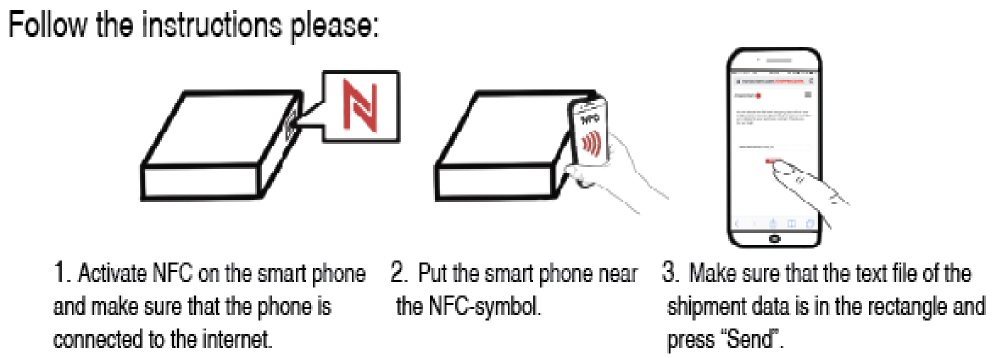


Figure 75: Storyboard for Sending Data

9.2 The Idea of a Mobile Application

An application has to be downloaded on the mobile phone. The application can be transmitted by using a QR code. The program uses NFC in order to connect with the smart package. When the phone is held next to the NFC symbol, the NFC will initiate automatically a connection via Bluetooth and data can be transferred to the phone. The application has to process the data for the purpose of creating a file, which is send back to Monocrom but which also reveals for the customer if the conditions of the shipment were proper or not.

The issue which has to be highlighted here is that programming a mobile application is out of the scope of the smart packaging team. Nevertheless, the idea how the application can look like is presented and may be used in the future development.

9.3 Layout of the Application

Since the application is simple, the layout consists of only a few parts:

1) In the instruction and storyboard is stated to scan the QR-code in order to download the Mobile Application.

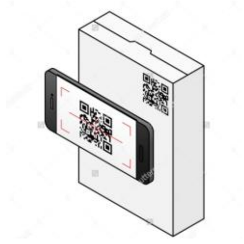


Figure 76: Scanning the QR Code

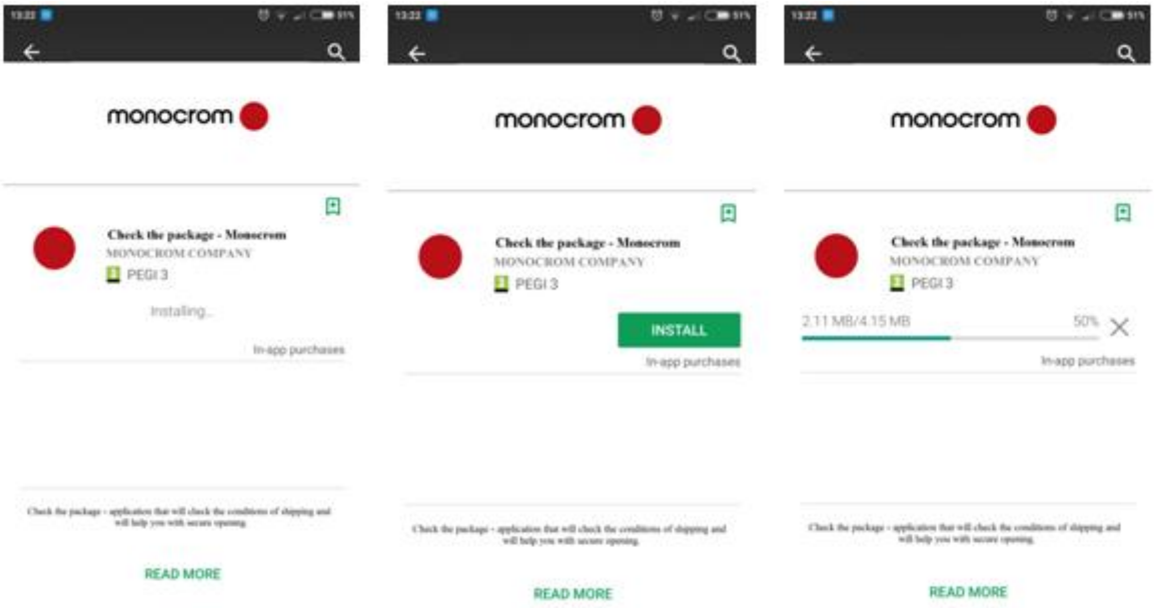


Figure 77: Downloading the Application

2) In the downloaded app the first page shows the information about the application.

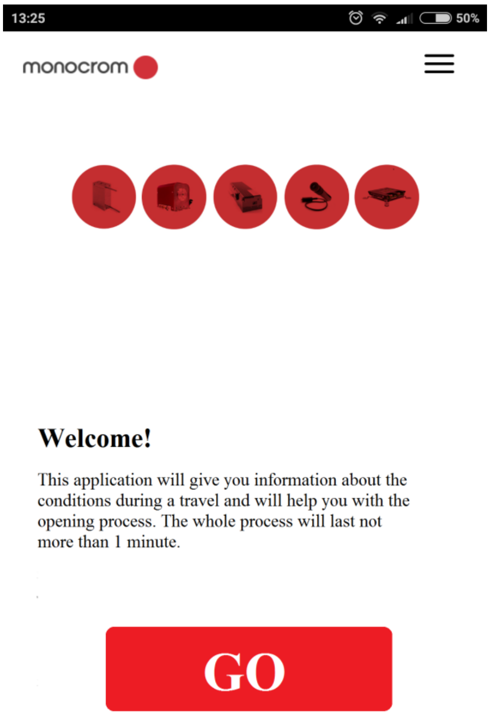


Figure 78: First Page of the Application

3) NFC picture/animation. It shows that a mobile should be put next to NFC sign in order to start the process of transferring and processing data.

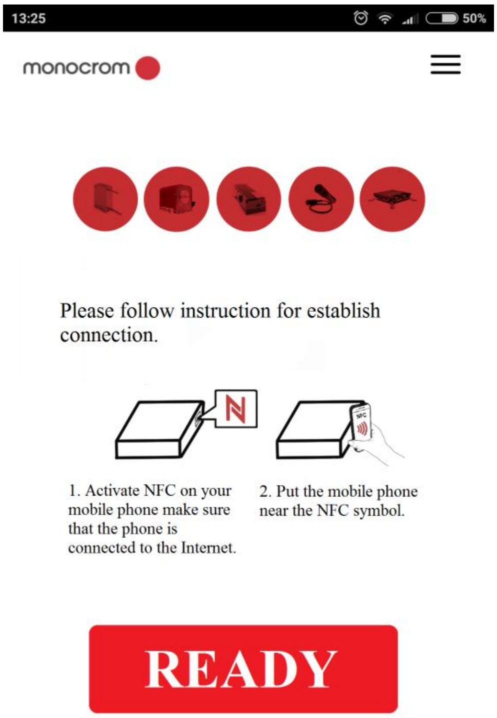


Figure 79: Instructions

4) Loading page. During this step the data is processed and it is send to Monocrom.

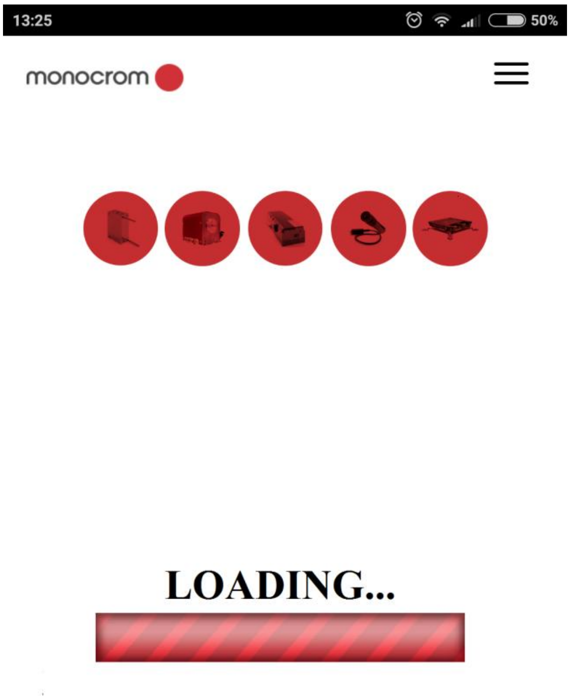


Figure 80: Loading Page

5) Button CHECK. By clicking this button, a customer will see if the conditions of the shipment were good or not.

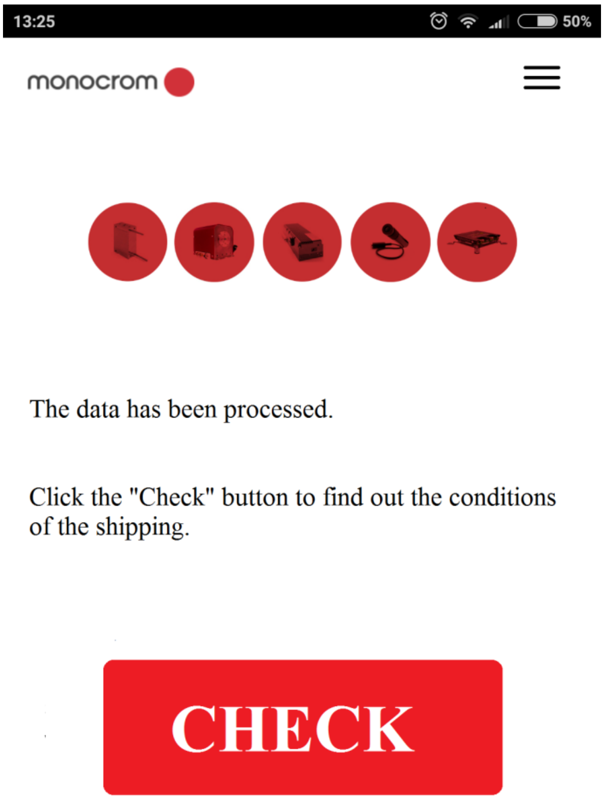


Figure 81: Check-Button

6) In the next step two options are possible: GOOD and BAD. In case of "GOOD" the customer is provided with the statement that the conditions of the shipment were proper and they are let through the instruction of how to open the box. In case of "BAD" there is the statement: "The conditions of the shipping were not proper. Please contact the company Monocrom as soon as possible in order to get further information".

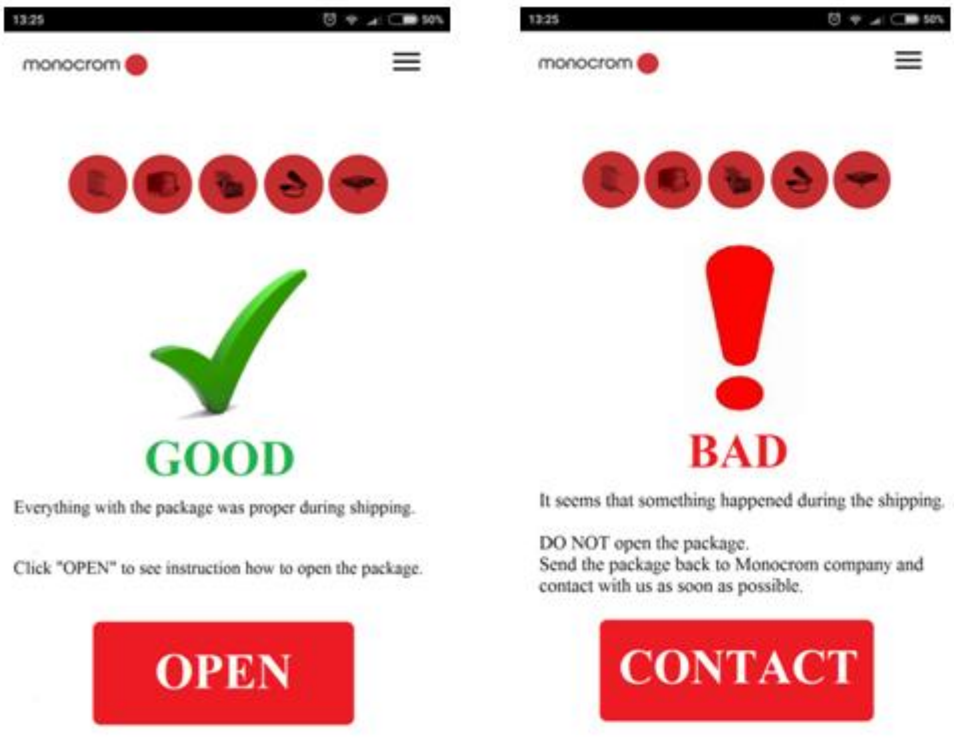


Figure 82: Shipment okay or not

7) Opening instruction. After clicking the "OPEN" button a storyboard of opening the package is appearing.

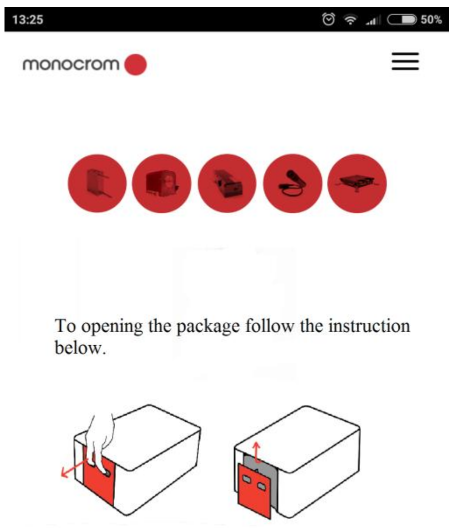


Figure 83: How to open the Box

10 Graphic Design

10.1 Graphic Design for the packaging Monocrom already uses

10.1.1Introduction

This cardboard package needs some extra information giving the customer the ability to know what he has to do when it arrives. It also needs some specifications about what exactly is inside and information about the company and the customer.

Therefore the team had to work on the graphics of the box, the stickers and the symbols to create a complete design of we had been asked to do.

10.1.2Symbols

First of all the team decided on the symbols that have to be on the cardboard box to show what kind of products are inside. This information is really important for the carrier because if he does not know that the product is fragile, for example, he will probably treat the box with less care and maybe the package arrives to the costumer with some broken products.

The symbols that we chose are the following ones:

- Fragile symbol: The laser devices that will be inside of the packaging are very sensitive. Because of that the project group decided to add two symbols, the glass and the fragile letters.

Figure 84: Fragile Symbols

- Opening symbol: The symbol seen on the opposite tells those handling the package that it must be stored the right way up. The arrows point towards the top of the package.

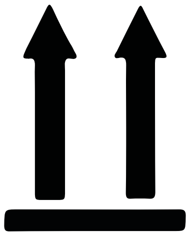


Figure 85: Opening Symbol

- Recycling symbol: That means that the box can be recycled.

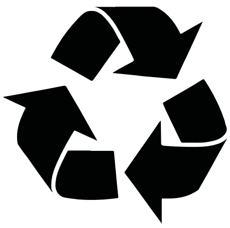


Figure 86: Recycling Symbol

10.1.3Monitoring Warning

The fact that sensors are in the packaging makes it necessary to notify to Monocrom's customers that the packaging is monitored. It is important that the customer knows that he should not act normal with this packaging; he has to follow the previous instructions. Therefore there is an extra sticker with the warning.

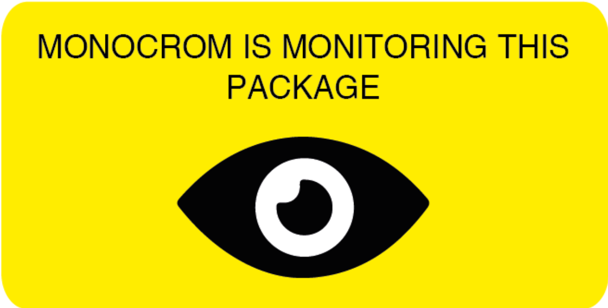


Figure 87: Monitoring Warning

10.1.4Instructions for the Customer

The aim of this project is to design a smart packaging, that means that it is not a normal package, it contains electronics. The customers do not have to act normal with this packaging, only opening the box; they have to follow some instructions to get the aim of this project: To know the circumstances of the products before opening the packaging and all the information about the travelling. The most important action is to send the data back to Monocrom because they want to know if their products arrive well.

These are the instructions on the cardboard box that the customers have to follow before opening the packaging:

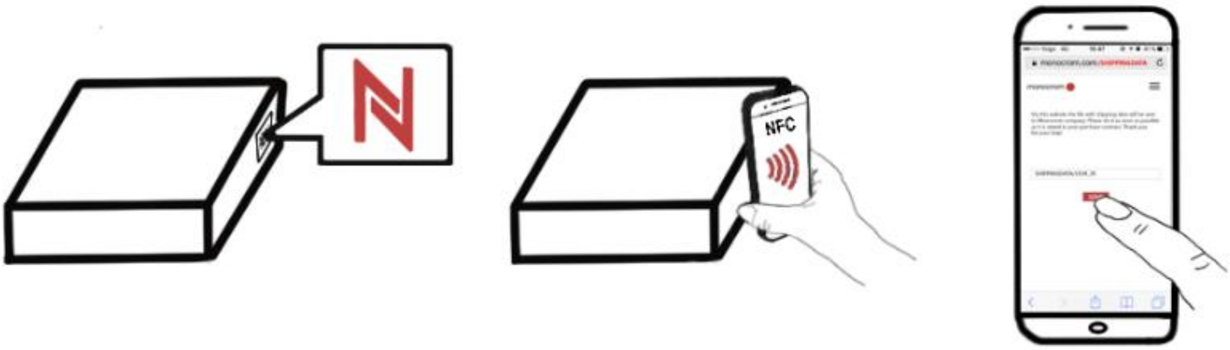


Figure 88: Instructions of how to access the Data

Though Monocrom and the team wanted to add a short text to explain the images to be sure that customers understand what to do.

1) Activate NFC on the smart phone and make sure that the phone is connected to the internet.
2) Put the smart phone near the NFC-symbol.
3) Make sure that the text file of the shipment data is in the rectangle and press "Send".

10.1.5Product Information

On the packaging it is also necessary to add the product information; one picture and the denomination.

Figure 89: Product Information Picture

And the product information and the instructions of how to get the data would be on the same sticker.

Figure 90: Main Sticker for Product Information and Instructions

On the following pictures it can be seen how the box looks like.

Figure 91: Stickers on the Cardboard Box

10.2 Graphic Design for the new Plastic Box

If finally Monocrom decides to apply the new plastic box idea, the stickers will be a slightly different.

Figure 92: The Plastic Box Design whithout Stickers

The main sticker with the product information and the instructions on how to get access to the data would be the same but placed on the plastic box, not on the cardboard one.

Figure 93: The Plastic Box with the main Sticker

This new plastic design has a special mechanism to open the box, making it safer for the products. And to be sure customers know how to open it there will be instructions on the same box.

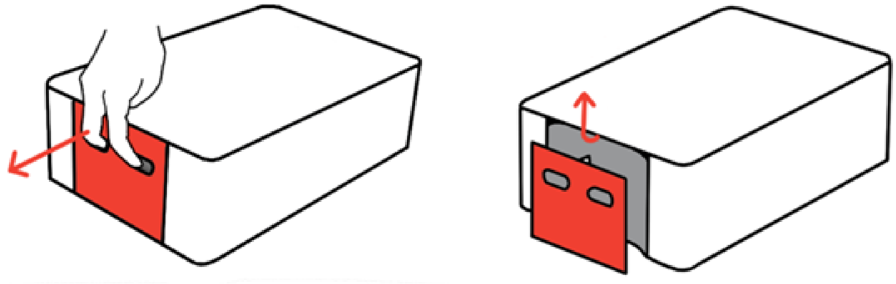


Figure 94: Instructions of how to open the Box

The instructions would be on the same piece which has to be removed.

Figure 95: Instructions on the Box

This new design for 4 laser devices needs a cardboard box for the shipment. On that cardboard box would be the sticker for the product information that Monocrom is using nowadays, see figure 96, the monitoring sticker, see figure 87, and fragile, opening and recycling symbols, see figures 84, 85 and 86.

Figure 96: The current Monocrom Sticker

11 Cost Estimation

11.1 Introduction

The cost for the smart packaging is a very important part to look at. As mentioned before the project group has to make sure that the cost for the packaging is no more than 100€ per package. In this section it is necessary to look at the two different solutions: 1. The big plastic box for 4 laser devices, which is put into the cardboard box for the shipment. 2. The solution for 4 existing small boxes, which contain one device each, and which will be put into a cardboard box for the transportation. The expenses of both options are differing.

11.2 Big Plastic Box for 4 Laser Devices

In this case the budget should include the prices for all the electronics, the gasket, foam, the material for the plastic box and for the stickers.

No.	Name	Price
1	Arduino Pro Mini ATMega328P 3.3V 8MHz	8.30 €
2	FTDI USB to Serial/UART TTL adapter CP2102	8.99 €
3	HC-08 Bluetooth 4.0 BLE Slave Module to UART Transceiver	7.99 €
4	DHT22 Digital Temperature Humidity Sensor AM2302 Module	7.28 €
5	ADXL377 High-g Triple-Axis (+-200g)	34.21 €
6	SPI Micro SD memory shield for Arduino	3.99 €
7	Dupont cables	1.05 €
8	3.7V 1200mAh Battery	4.00 €
9	Permatex 81160 High-Temp Red RTV Silicone Gasket, 3 oz	3.55 €
10	Foam	10.12 €
11	ABS for Box	1.75 €
12	Stickers	5.00 €
13	Sum	96.23 €

Table 17: Cost for big Plastic Box Solution

It is possible to stay in the budget of 100€ with this solution, as can be seen in table 17. But it is has to be considered that the company bought the components only for one box. If Monocrom uses this solution in the future, the company can buy the components in bulk and the prices may decrease, according to the economies of scale of the suppliers. The company can also try to negotiate with the suppliers in order to receive a better offer. Another possible way to reduce costs is to look for other suppliers.

11.3 4 Small Boxes in one Cardboard Box for Shipment

The costs for this solution are referred to the electronics and the stickers, see table 18.

No.	Name	Price
1	Arduino Pro Mini ATMega328P 3.3V 8MHz	8.30 €
2	FTDI USB to Serial/UART TTL adapter CP2102	8.99 €
3	HC-08 Bluetooth 4.0 BLE Slave Module to UART Transceiver	7.99 €
4	DHT22 Digital Temperature Humidity Sensor AM2302 Module	7.28 €
5	ADXL377 High-g Triple-Axis (+-200g)	34.21 €
6	SPI Micro SD memory shield for Arduino	3.99 €
7	Dupont cables	1.05 €
8	3.7V 1200mAh Battery	4.00 €
9	Stickers	3.00 €
10	Sum	78.81 €

Table 18: Cost for Cardboard Box Solution

It can be identified, that with this solution the company would stay in the budget.

12 Ecodesign of the Smart Packaging

12.1 Introduction

Considering the ecological point of view the team performed several steps in order to make the smart packaging environmentally friendly. During working on the project, ecological thinking and designing were important issues.

12.2 Amount of Transported Devices

At the beginning of the project, the main assumption was to control the shipping conditions for one laser device in one package. The budget for the smart package was no more than 25€. Assembling all the electronic devices like the microcontroller, sensors and others with a plastic box, foam and labelling in this case was not possible with this budget. An important change has been done to solve the problem. Firstly, an interview was conducted with the company Monocrom to identify how many products they send to one customer. In the response, it was stated that mostly the company sends 4, 8 or 12 products to one destination. Rarely more than 12 products are shipped. Because of this fact, the team has established that one smart package will contain 4 products. Thanks to that the budget has been increased to 100€. Moreover, the package is designed for 4 products not for 1, which gave the team the opportunity to decrease the amount of electronics. Right now, the electronic equipment is needed for 4 laser devices, not only for one. On the other hand, the package is bigger but it can be manufactured regarding the new budget.

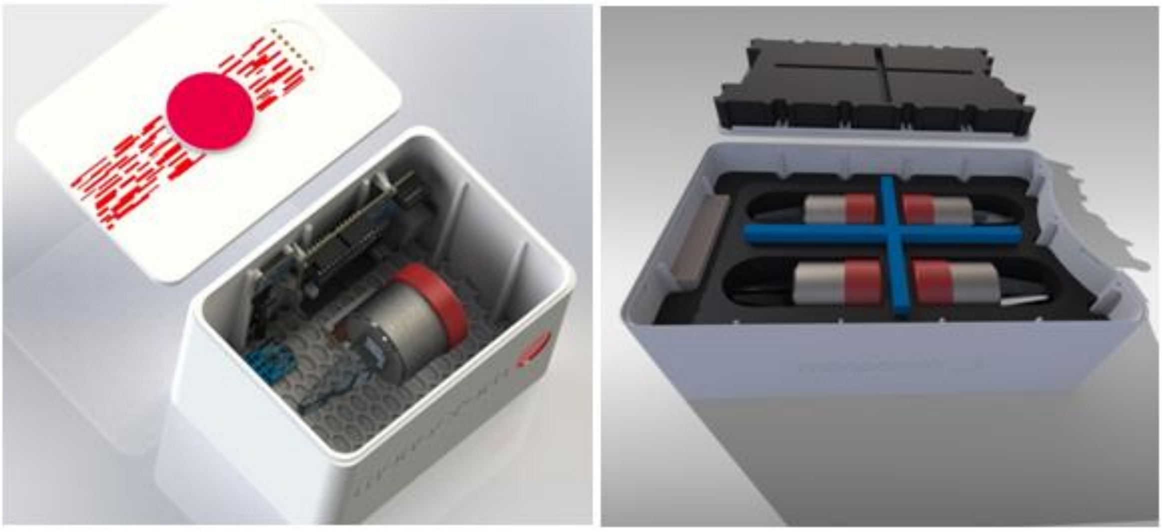


Figure 97: Old and New Solution

12.3 Feature inside of the Smart Packaging

Inside the package are special walls which divide the interior of the box and separate the laser devices. If the box is without contents, it can be used for storing bolts, nuts or other things. So after receiving the package by the customer, they can reuse it later for whatever they want. Additionally, the interior can be divided using those special walls.

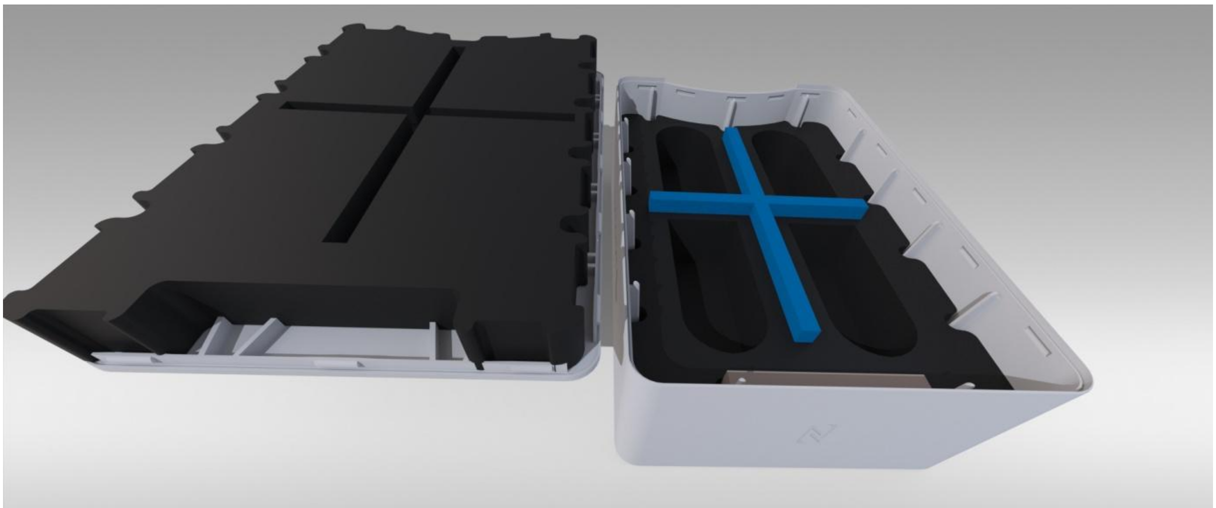


Figure 98: The Seperating Walls

12.4 The Cardboard Box

The smart package will be put inside a cardboard box on which all necessary labels for the courier will be attached. This box can be recycled and an appropriate sign will be added on it.

Figure 99: Ecofriendly Labels

13 Future of Smart Packaging

As of now, we have yet to implement a suitable battery for our smart packaging because some practical test still need to be done and it requires more time. Some of the electronics are very sensitive to low voltage and will not properly operate even though their LED still light up. There is a possibility that the electronics might need a high capacity battery to operate properly until the end of the shipment especially the ones with longer shipping period.

This current version of smart packaging uses two separate types of wireless communication to retrieve data from the package, NFC is used to establish a Bluetooth connection between the package and the smart phone and an automated program will send a file to the smart phone with data indicating the condition of the contents of the package. Once the data has been received by the customer they will automatically be taken to Monocrom's webpage and will be required to send this data file back to Monocrom.

This process has its drawbacks as it heavily relies on the customer to return the data to Monocrom after reading the data for themselves, the next step is to design an application that eliminates the last step, the customer will need to download a custom Monocrom application and the data will be received by the application in the same way but will automatically be sent to Monocrom while indicating to the customer the diodes condition.

In the future, the smart package could possibly be developed to operate independently without the need for a smart phone, when the price of electronics drops to a more reasonable price a touch screen display could be incorporated to display real time information or a password could be used to protect the information. To send the data back to Monocrom a Wi-Fi module could also be incorporated to connect to the internet.

Strengths	**Weaknesses**
Robust Design. Simple Design. Watertight.	High Power Consumption. Can only be hermetically sealed once. Electronics only used once.
Opportunities	**Threats**
Possibility to create application. Could be applied in many different industries.	None of our Designs are patented.

Table 19: SWOT Analysis

14 References

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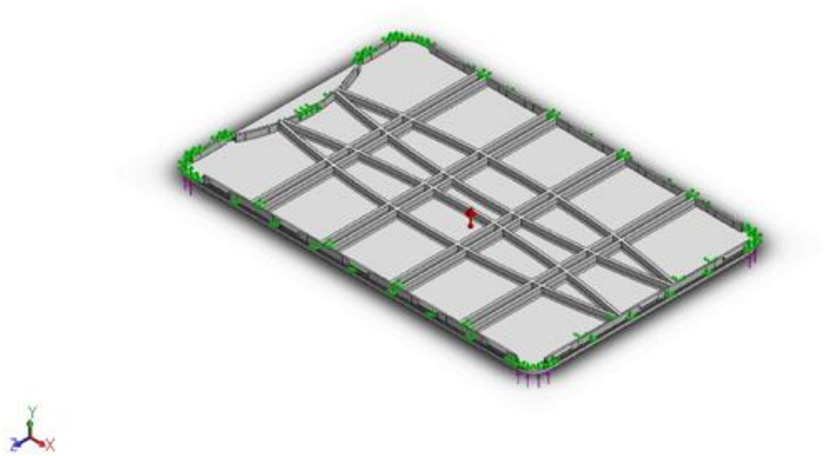
15 Appendix

Appendix 1. Lid Test

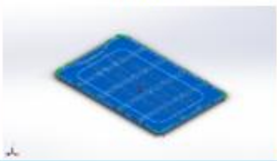
Simulation LID Stress

Model Information



Model name: lid3 Stress
Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties
Fillet33 	Solid Body	Mass:0.237128 kg Volume:0.000232478 m^3 Density:1020 kg/m^3 Weight:2.32385 N

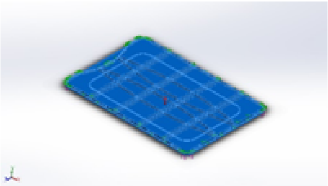
Study Properties

Study name	Static
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off

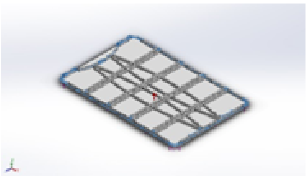
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

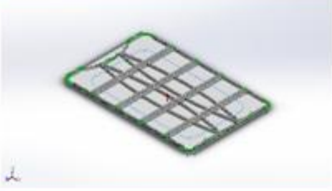
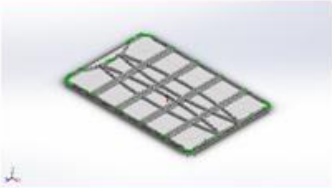
Model Reference	Properties
	Name: ABS Model type: Linear Elastic Isotropic Default failure criterion: Unknown Tensile strength: 3e+007 N/m^2 Elastic modulus: 2e+009 N/m^2 Poisson's ratio: 0.394 Mass density: 1020 kg/m^3 Shear modulus: 3.189e+008 N/m^2

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: 11 edge(s), 3 face(s) Type: Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0.00213058	-62.3295	-0.00250594	62.3295
Reaction Moment(N.m)	0	0	0	0

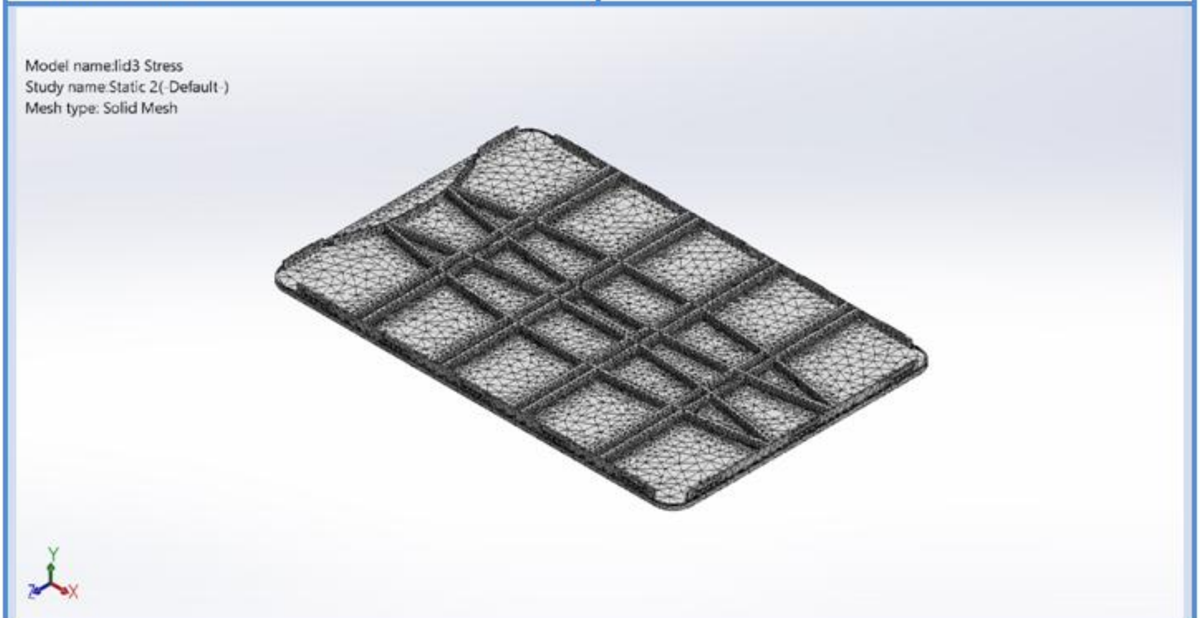
Load name	Load Image	Load Details
Force-1		Entities: 3 face(s) Type: Apply normal force Value: 60 N
Gravity-1		Reference: Face< 1 > Values: 0 0 9.81 Units: SI

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points	29 Points
Maximum element size	8.27608 mm
Minimum element size	1.65522 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	232355
Total Elements	128516
Maximum Aspect Ratio	1335.8
% of elements with Aspect Ratio < 3	64.2
% of elements with Aspect Ratio > 10	7.39
% of distorted elements(Jacobian)	0.393
Time to complete mesh(hh;mm;ss):	00:00:22
Computer name:	



Resultant Forces

Reaction forces

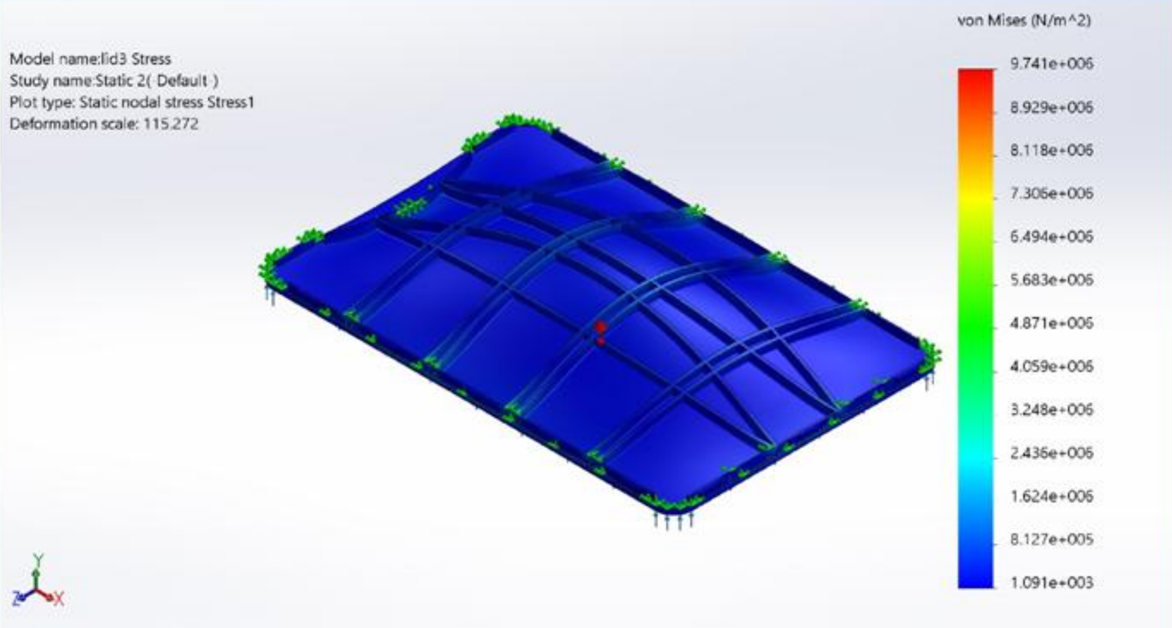
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.00213058	-62.3295	-0.00250594	62.3295

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

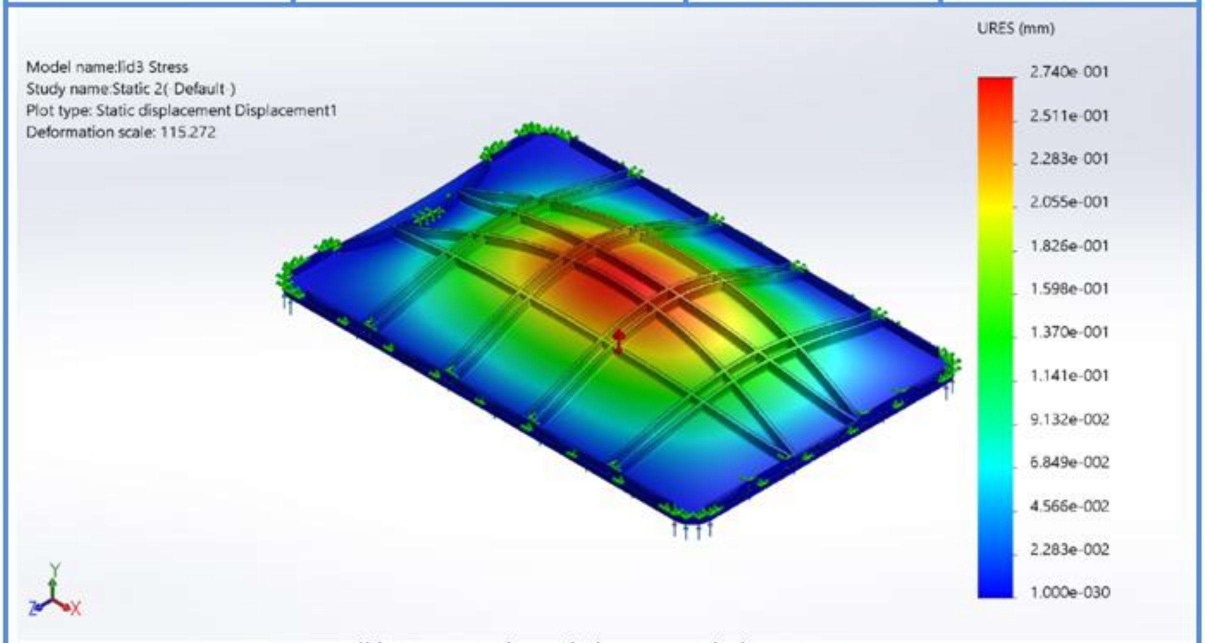
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1090.83 N/m^2 Node: 12096	9.741e+006 N/m^2 Node: 69202



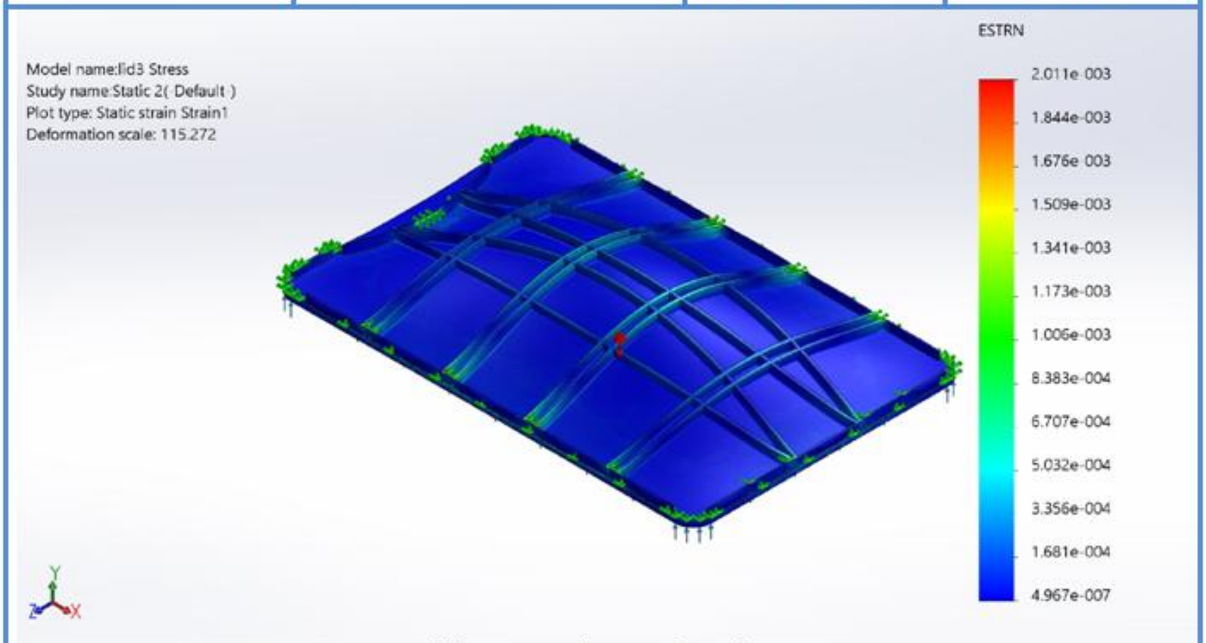
lid3 Stress-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 354	0.27396 mm Node: 169297



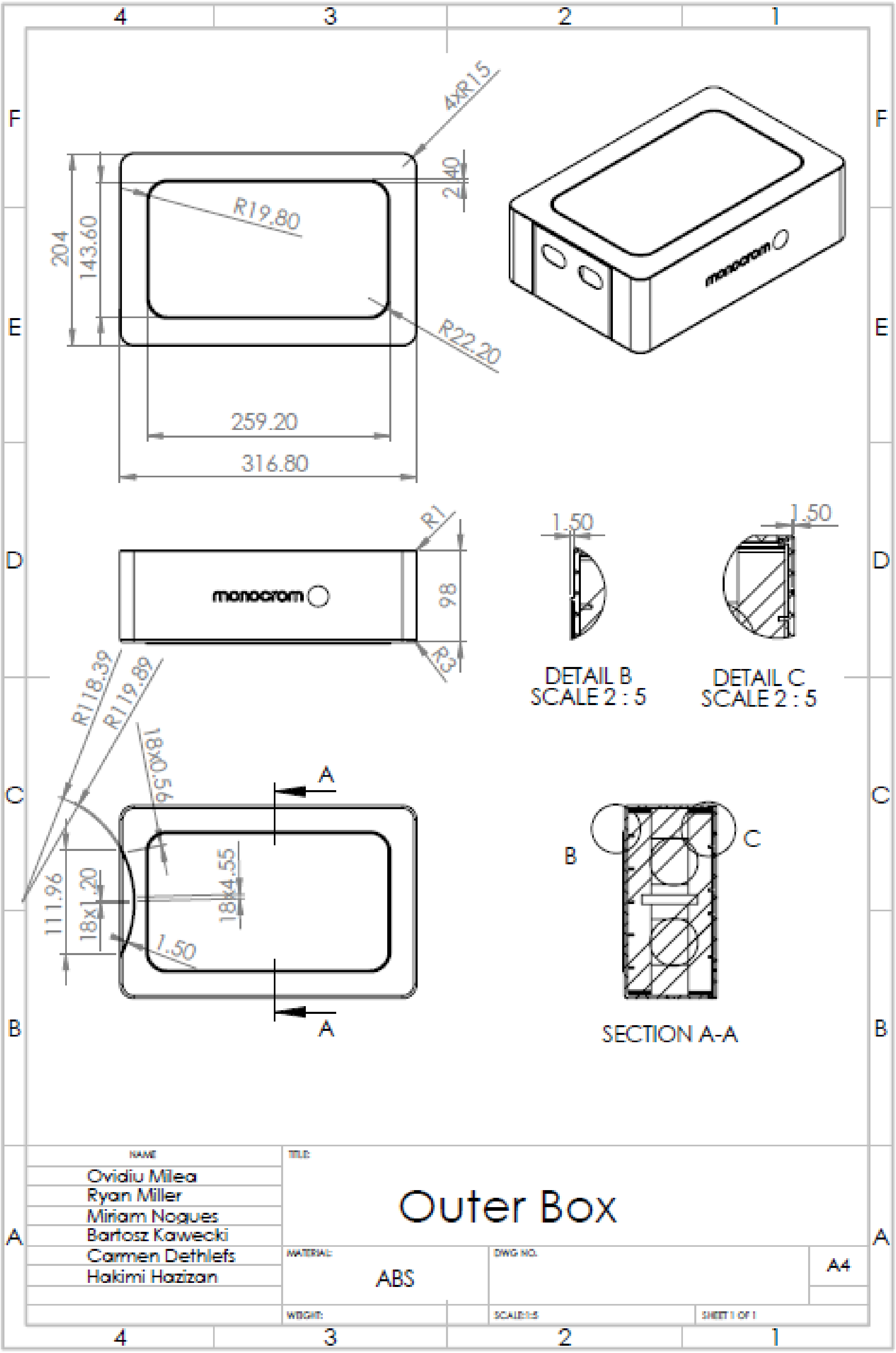
lid3 Stress-Static 2-Displacement-Displacement1

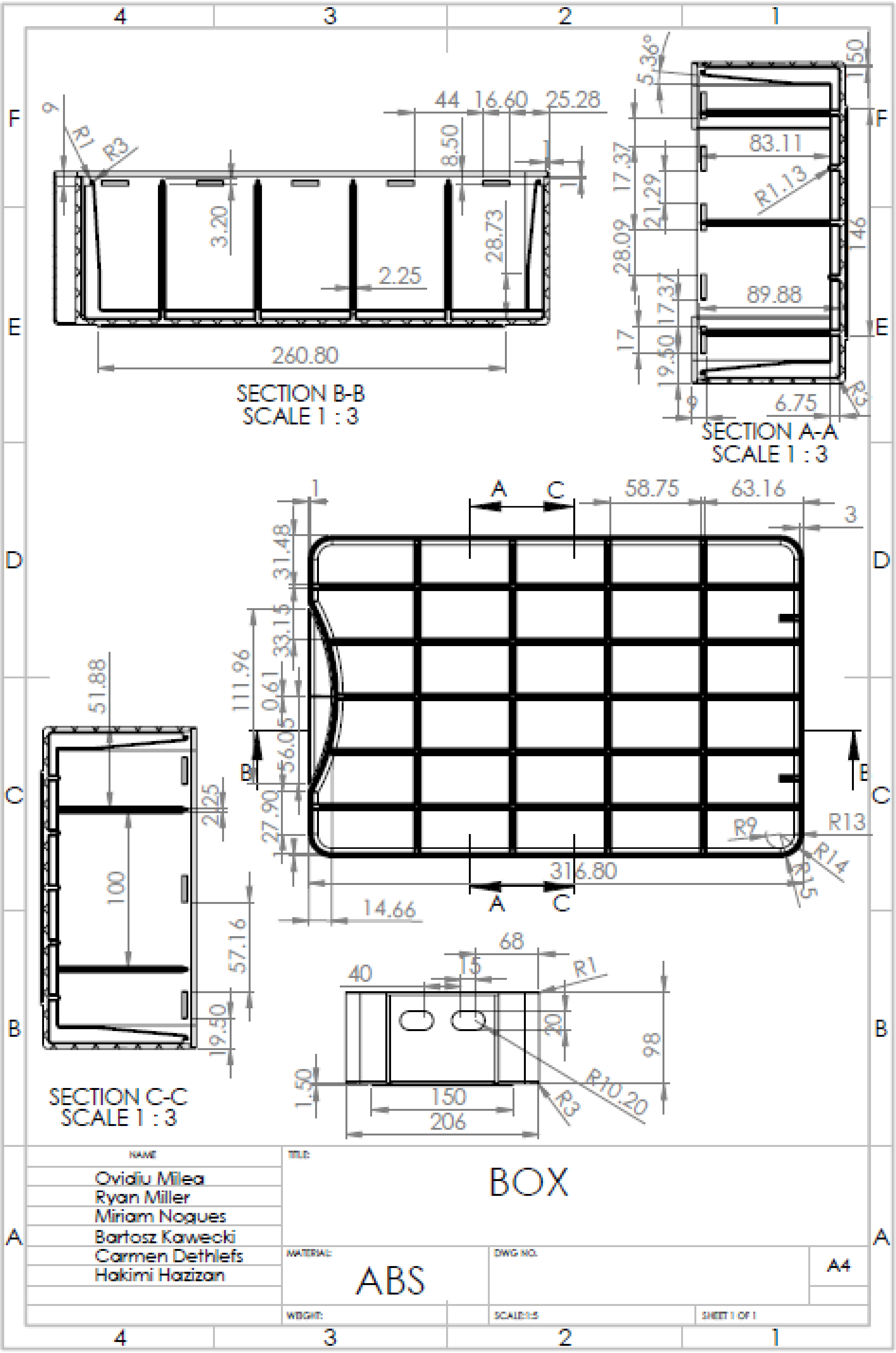
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	4.96667e-007 Element: 50391	0.00201119 Element: 91123

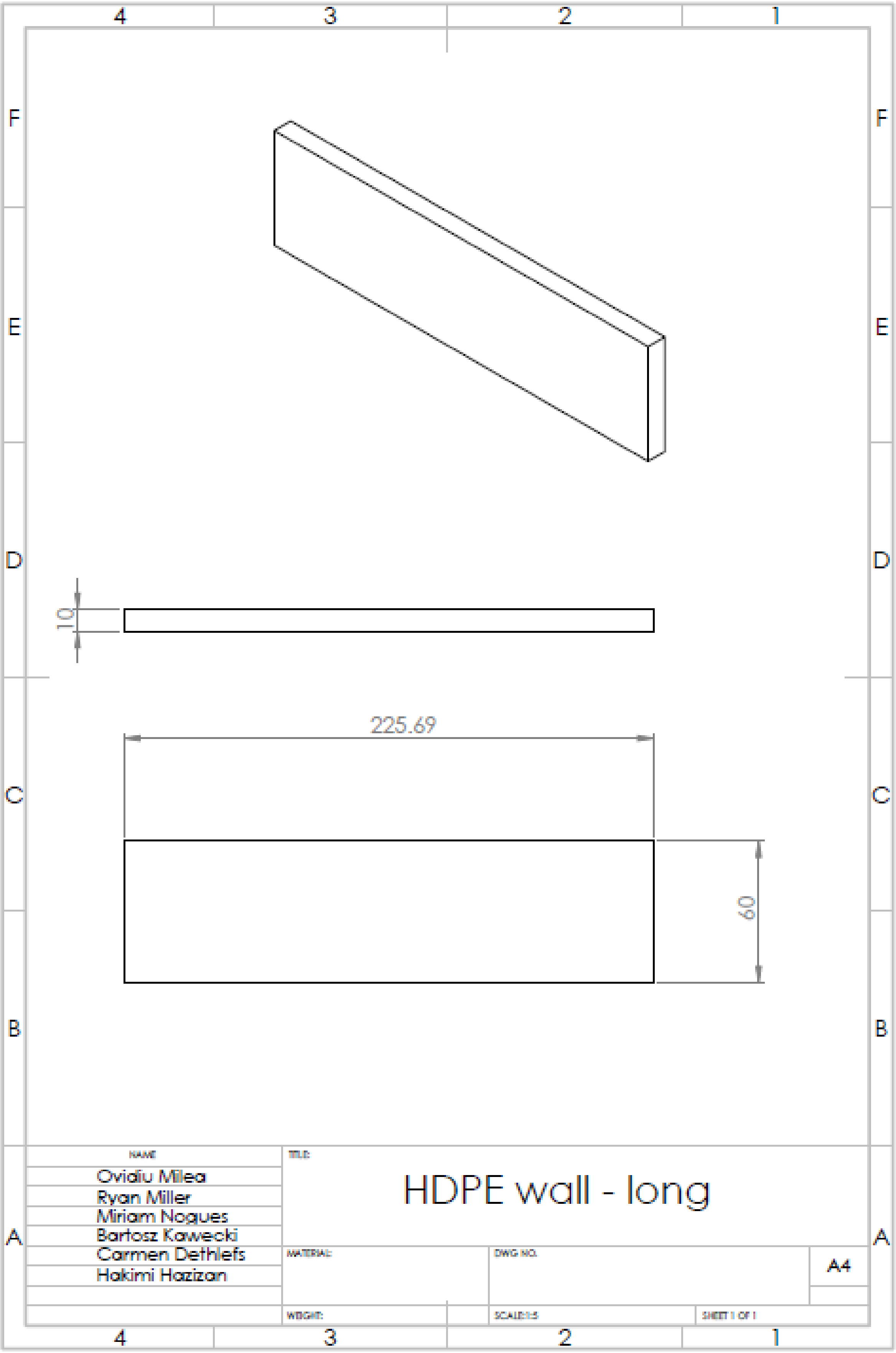


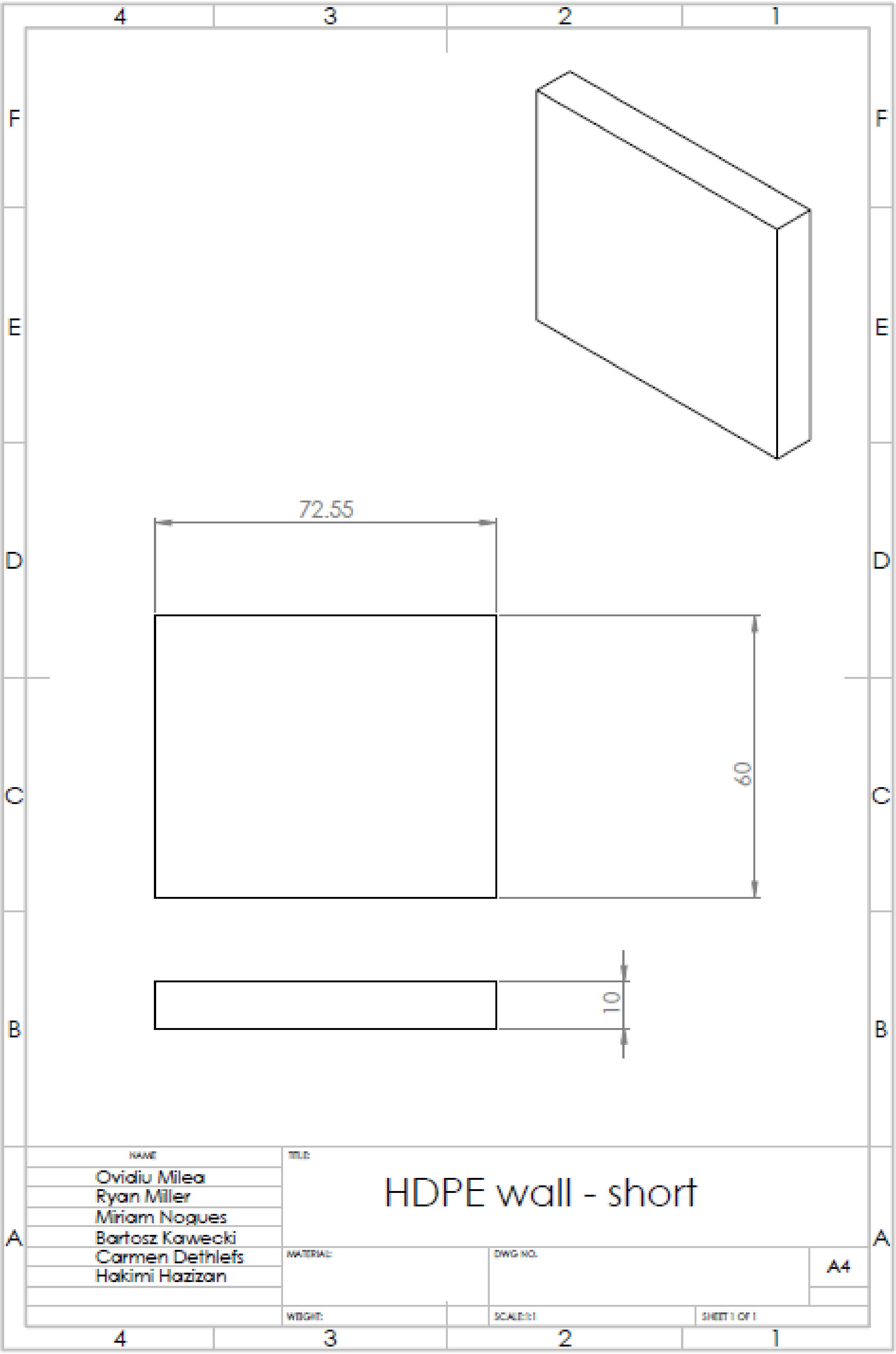
lid3 Stress-Static 2-Strain-Strain1

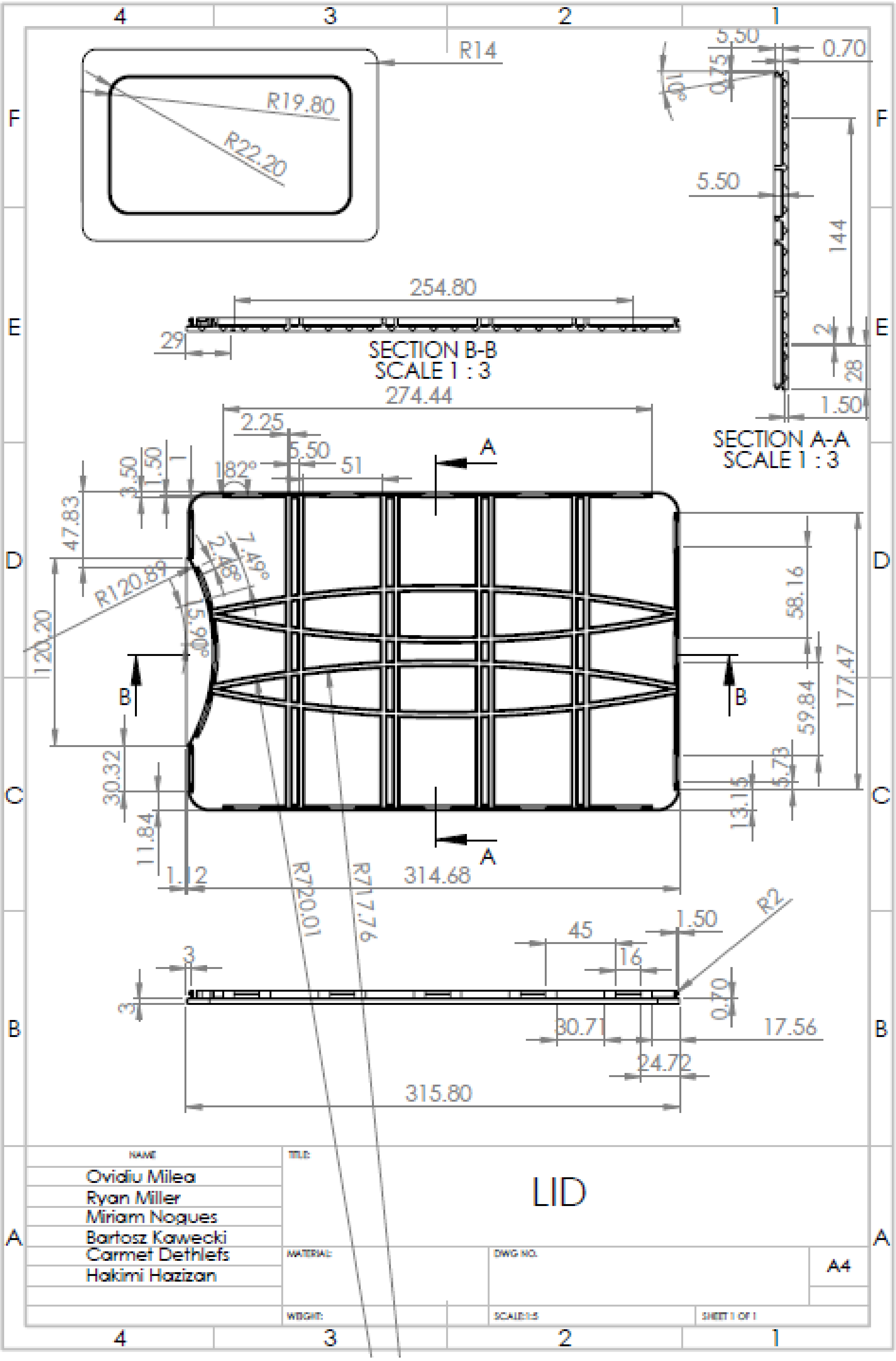
Appendix 2. Drawings

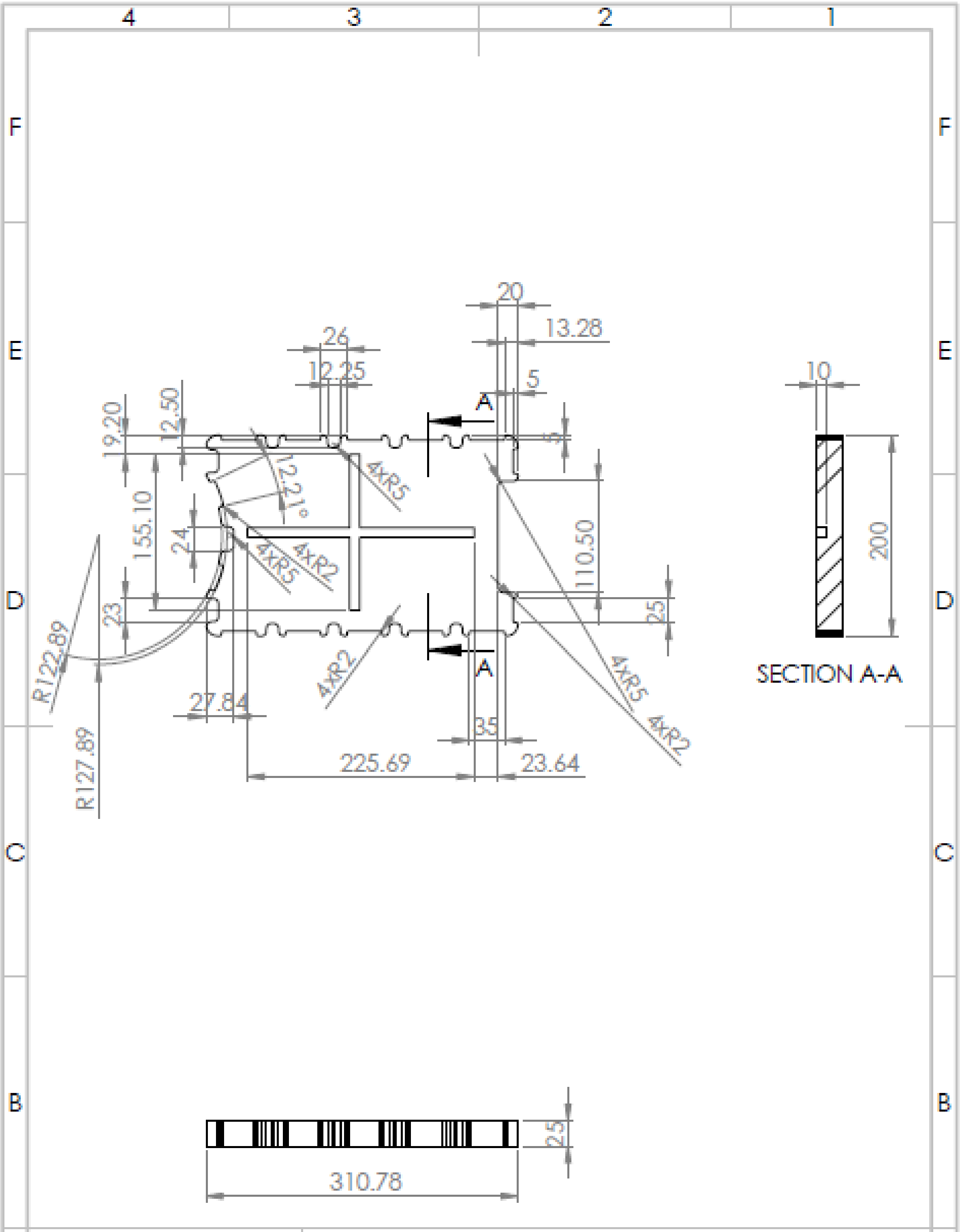



SECTION B-B
SCALE 1 : 3
SECTION A-A
SCALE 1 : 3
SECTION C-C
SCALE 1 : 3
44
16.60
25.28
8.50
3.20
28.73
2.25
260.80
5.36°
50
83.11
R1.13
146
89.88
17.37
21.29
28.09
17
19.50
6.75
R3
58.75
63.16
31.48
33.15
111.96
0.61
56.05
27.90
316.80
14.66
R9
R13
R14
R15
51.88
2.25
100
57.16
68
40
15
R1
20
98
150
206
R10.20
1.50
NAME
Ovidiu Milea
Ryan Miller
Miriam Nogues
Bartosz Kawecki
Carmen Dethlefs
Hakimi Hazizan
TITLE:
BOX
MATERIAL:
ABS
DWG NO.
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1

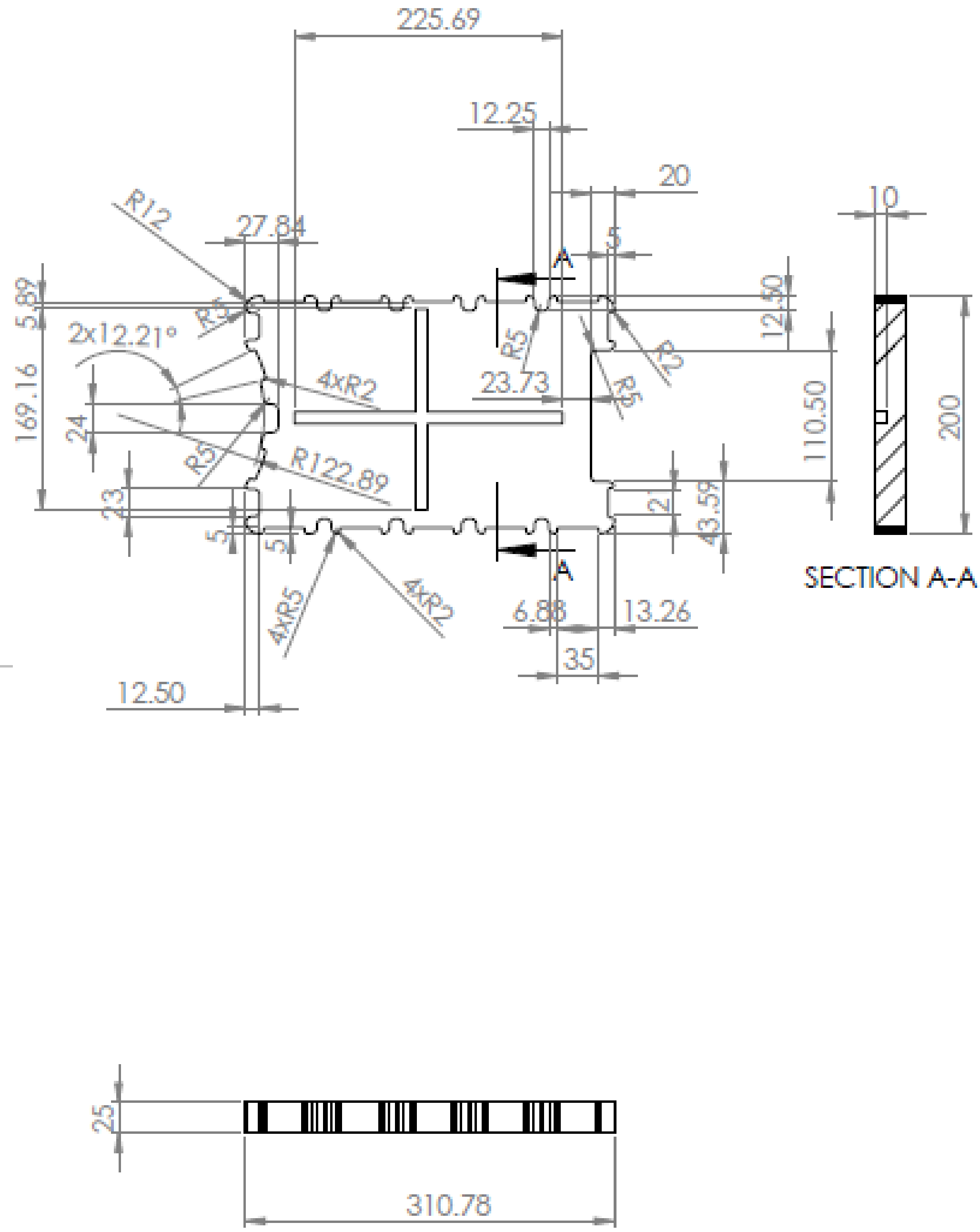

10
225.69
60
NAME
Ovidiu Milea
Ryan Miller
Miriam Nogues
Bartosz Kawecki
Carmen Dethlefs
Hakimi Hazizan
TITLE:
HDPE wall - long
MATERIAL:
DWG NO.
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1


72.55
60
10
NAME
Ovidiu Milea
Ryan Miller
Miriam Nogues
Bartosz Kawecki
Carmen Dethlefs
Hakimi Hazizan
TITLE:
HDPE wall - short
MATERIAL:
DWG NO.
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1


R14
R19.80
R22.20
254.80
SECTION B-B
SCALE 1 : 3
SECTION A-A
SCALE 1 : 3
274.44
314.68
315.80
R720.01
R717.76
R120.89
177.47
LID
Ovidiu Milea
Ryan Miller
Miriam Nogues
Bartosz Kawecki
Carmet Dethlefs
Hakimi Hazizan
A4



NAME	TITLE:
Ovidiu Milea	Low Density Foam - top
Ryan Miller	
Miriam Nogues	
Bartosz Kawecki	MATERIAL: / DWG NO. / A4
Carmen Dethlefs	
Hakimi Hazizan	
	WEIGHT: / SCALE:1:5 / SHEET 1 OF 1



NAME	TITLE: Low Density Foam - bottom
Ovidiu Milea	
Ryan Miller	
Miriam Nogues	
Bartosz Kawecki	
Carmen Dethlefs	
Hakimi Hazizan	

MATERIAL:

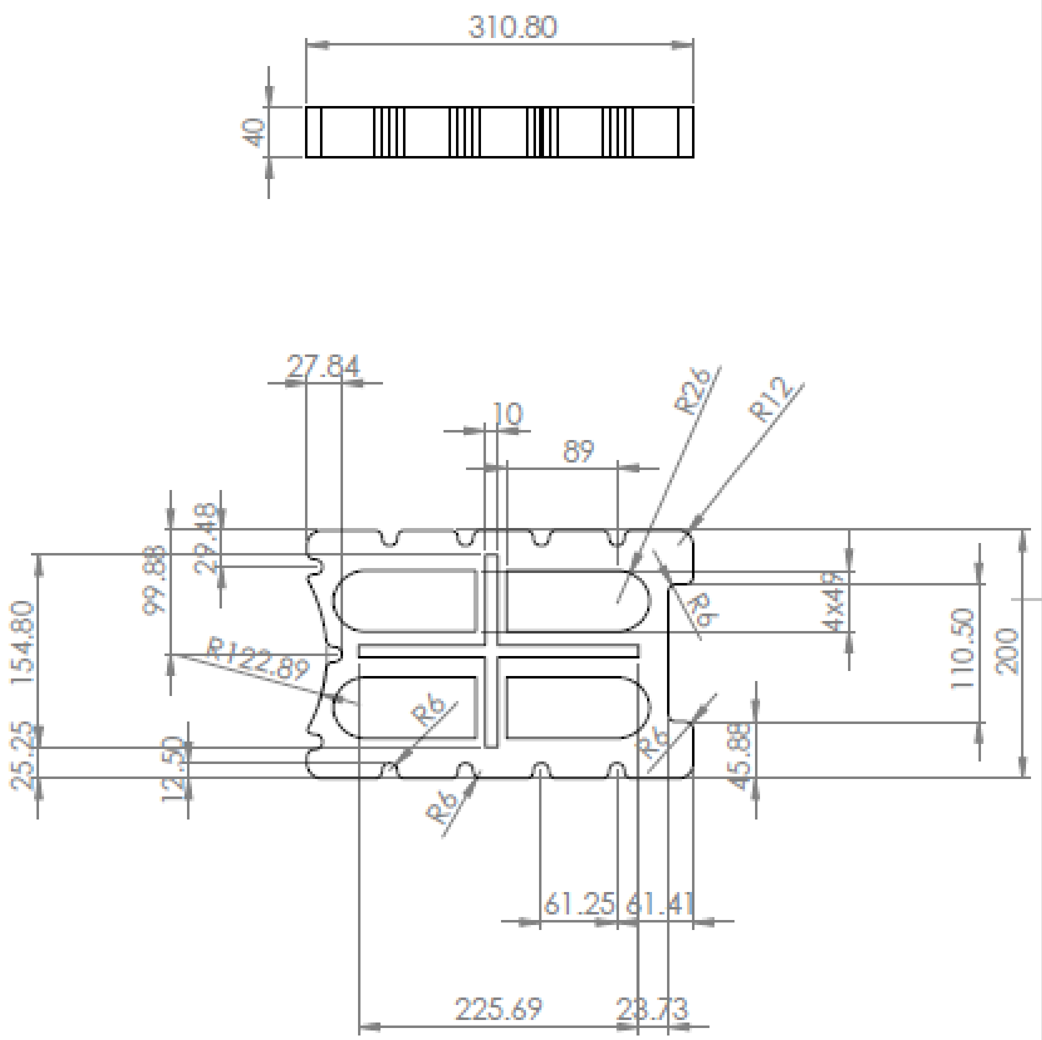
DWG NO.

A4

WEIGHT:

SCALE:1:5

SHEET 1 OF 1



NAME	TITLE:
Ovidiu Milea	High Density Foam
Ryan Miller	
Miriam Nogues	
Bartosz Kawecki	
Carmen Dethlefs	
Hakimi Hazizan	

MATERIAL:

DWG NO.

A4

WEIGHT:

SCALE:1:5

SHEET 1 OF 1

Appendix 3. Arduino Code

```
#include <SPI.h>
#include <SD.h>
#include <DHT.h>

#define DHTPIN 9                              //Define out pin for DHT22
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);

File myFile;                                  //Define required variables
int scale = 200;
int ms = 0;
int s, m, h, d;
int Tmax, Hmax;
float scaledX, scaledY, scaledZ;
int x, y, z, conn;
int Gmax, GMAX;
int Vmax, VMAX, vtime;
bool Vvalue;
float hum, temp;
long previousTime = 0;
long interval = 20;

void setup () {
 Serial.begin (9600);                         //Set baud rate to 9600
 dht.begin();                                 //Start temperature and humidity sensor
 while (!Serial) {
   ;
 }
 myFile = SD.open("log.txt", FILE_WRITE);
 if (!SD.begin(10)) {
  Serial.println("initialization failed!");   //Display error if necessary
  return;
 }
}
```

```
void loop () {
  unsigned long currentTime = millis();                  //Save current milisecond
  if ( currentTime - previousTime > interval){          //Create a delay of 20ms for each loop
    previousTime = currentTime;
    ms = ms + 1;
    if (ms == 50){                                       //When reach 1s
      timeCount();                                       //Execute timeCount
    }
    TempHumCheck();                                      //Do a temperature and humidity check
    AccelCheck();                                        //Read data from the acce;erometer
  }
}

void TempHumCheck () {
   hum = dht.readHumidity();                             //Read value for humidity
   temp= dht.readTemperature();                          //Read value for temperature
   if (temp > Tmax){                                     //Check if current temperature is higher
                                                         //than the maximum temperature
     Tmax = temp;                                        //Save the maximum temperature
   }
   if (hum > Hmax){                                      //Check if current humidity is higher
                                                         //than the maximum humidity
     Hmax = hum;                                         //Save the maximum temperature
   }
}

void AccelCheck (){
  int rawX = analogRead(A0);                             //Read raw values from the accelerometer
  int rawY = analogRead(A1);
  int rawZ = analogRead(A2);
  scaledX = fabs(map(rawX, 0, 1023, -scale, scale));     //Convert the raw values into g's
  scaledY = fabs(map(rawY, 0, 1023, -scale, scale));
  scaledZ = fabs(map(rawZ, 0, 1023, -scale, scale));
  if (scaledX > 1 || scaledY > 1 || scaledZ > 1){        //Check if any axis has a value more than 1 g
```

```
  if (!Vvalue){                                        //Check if x, y and z already has values
   x = scaledX;                                        //Save the values
   y = scaledY;
   z = scaledZ;
   Vvalue = true;                                      //Mark x, y and z to have values
  }
  if (scaledX == x || scaledY == y || scaledZ == z){   //Check if any current value from the accelerometer
                                                       //coincide with the previous values
   vtime = vtime + 1;                                  //Increase the counter for vibration time
   if (vtime == 100){                                  //Check if the vibration time reaches 2
                                                       //seconds
    if (scaledX == x){                                 //Check if x-axis value is the same as previous
     Vmax = scaledX;                                   //Save the value for maximum vibration
     if (scaledY == y && scaledY > Vmax){              //Check if y-axis value is the same as previous
                                                       //and larger than current value
      Vmax = scaledY;                                  //Save the value for maximum vibration
      if (scaledZ == z && scaledZ > Vmax){             //Check if z-axis value is the same as previous
                                                       //and larger than current value
       Vmax = scaledZ;                                 //Save the value for maximum vibration
      }
     }
    }else if (scaledY == y){                           //Check if y-axis value is the same as previous
     Vmax = scaledY;                                   //Save the value for maximum vibration
     if (scaledZ == z && scaledZ > Vmax){              //Check if z-axis value is the same as previous
                                                       //and larger than current value
       Vmax = scaledZ;                                 //Save the value for maximum vibration
     }
    }else{
     Vmax = scaledZ;                                   //Save the value for maximum vibration
    }
    if (Vmax > VMAX){                                  //Check if current maximum value is larger
                                                       //than previous maximum value
     VMAX = Vmax;                                      //Save current maximum value for vibration
    }
    vtime = 0;                                         //Reset counter for vibration time
```

```
    }
   }else{
    Vvalue = false;                                 //Mark x, y and z to have no values
    vtime = 0;                                      //Reset counter for vibration time
   }
  }else{
   Vvalue = false;                                  //Mark x, y and z to have no values
   vtime = 0;                                       //Reset counter for vibration time
  }
  Gmax = scaledX;                                   //Save the x-axis value as maximum value
  if (scaledY > Gmax){                              //Check if y-axis value is more than current
maximum value
   Gmax = scaledY;                                  //Save the y-axis value as maximum value
  }
  if (scaledZ > Gmax){                              //Check if y-axis value is more than current
maximum value
   Gmax = scaledZ;                                  //Save the z-axis value as maximum value
  }
  if (Gmax > GMAX){                                 //Check if current maximum value is
                                                    //larger than previous maximum value
   GMAX = Gmax;                                     //Save current maximum value for shock
  }
}

void timeCount (){                                  //this funtion act as a timer
  ms = 0;
  s = s + 1;
  conn = conn + 1;
  if (conn == 5){
   conn = 0;
   if (Serial){                                     //Check if there is any serial connection
    sendToBluetooth();                              //Send data to serial
   }
  }
  if (s == 60){
   s = 0;
```

```
  m = m + 1;
  if (m == 60){                                    //Execute these once every hour
    m = 0;
    h = h + 1;
    writetoSD();                                   //Write necessary data to SD card
    Tmax = 0;                                      //Reset the maximum values
    Hmax = 0;
    VMAX = 0;
    GMAX = 0;
    if (h == 23){
      h = 0;
      d = d + 1;
    }
  }
 }
}

void writetoSD () {
  myFile = SD.open("log.txt", FILE_WRITE);         //Open LOG.txt on the SD card
 if (myFile) {
  myFile.print(d); myFile.print(" day(s) ");       //Log the maximum temperature of the hour
  myFile.print(h); myFile.print(" hour(s) ");
  myFile.println("after the package was sent");
  myFile.print("Max. Temperature    : ");
  myFile.print(Tmax); myFile.print("C ... ");
  if (Tmax < 60) {                                 //Determine whether the parameter is OK or
not
    myFile.println("OK");
  }else{
    myFile.println("NOT OK");
  }
  myFile.print("Max. Humidity       : ");          //Log the maximum humidity of the hour
  myFile.print(Hmax); myFile.print("%  ... ");
  if (Hmax < 80) {                                 //Determine whether the parameter is OK or
not
    myFile.println("OK");
```

```
  }else{
    myFile.println("NOT OK");
  }
  myFile.print("Max. g for vibration: ");              //Log the maximum vibration of the hour
  myFile.print(VMAX); myFile.print("g  ... ");
  if (VMAX < 30) {                                      //Determine whether the parameter is OK or
not
    myFile.println("OK");
  }else{
    myFile.println("NOT OK");
  }
  myFile.print("Max. g for shock    : ");              //Log the maximum shock of the hour
  myFile.print(GMAX); myFile.print("g  ... ");
  if (GMAX < 50) {                                      //Determine whether the parameter is OK or
not
    myFile.println("OK");
    myFile.println("");
  }else{
    myFile.println("NOT OK");
    myFile.println("");
  }
  myFile.close();                                       //Close LOG.txt
 } else {
  Serial.println("error opening log.txt");              //Display error there is any
 }
}

void sendToBluetooth (){
 myFile = SD.open("log.txt");                           //Open LOG.txt on the SD card
 if (myFile) {
  while (myFile.available()) {
    Serial.write(myFile.read());                        //Read everything on the SD card
    delay(12);
  }
  myFile.close();                                       //Close LOG.txt
 } else {
```

```
    Serial.println("error opening log.txt");                    //Display error there is any
  }
}
```