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Radio Frequency Interference
PDS 100
EPS project

Doble Engineering

EPS Glasgow


GCU
Glasgow Caledonian
University

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1. EXECUTIVE SUMMARY

Electricity surrounds us everywhere. Light, cooking appliances or electronic devices became an evidence for the world, but what people forget is that electricity has a big journey to undertake before getting to the little user. This journey is actually not an evidence and could be very dangerous due to high voltages or other problems. Electrical substations, one of the main parts of the electrical road, are exposed to many problems, among them partial discharge. Doble engineering created a product, the PDS100, to localise and measure this problem and in that way assure a safe and costless journey.

In substations, a lot of expensive machinery and equipment are exposed to high voltage stress. If this circumstance is combined with ageing, deterioration of the equipment can happen which can lead to big accidents such as explosions. The PDS100 is used in proactive maintenance to detect problems at its early stages and in that way avoiding big accidents.

The PDS100 is a very successful, accurate and functional product and a market leader in detecting partial discharge. Despite this, improvements on the product are possible. The product was designed some years ago and does not take advantage of the disruptive technologies that have appeared in the recent years. Improvements on the product, the usability and human interaction maintaining its accuracy are needed.

A design for a new product that takes advantages of disruptive technologies such as augmented reality has been created. The final design is divided in three parts, one utility belt, called the backpack device, with the battery and the device itself that detects the partial discharge, a forearm wearable wearing a tablet for the interface and the handheld antenna. A prototype of the application has also been designed in order to simulate the different functionalities and features taking today's expectations of interaction into consideration. The device is capable of saving measurements taken in the substations and associate it with the position where it has been taken. This makes the device able to compare between successive measurements made.

The proposed design makes personalization possible for the purchaser, depending on the needs, by being able to choose between two different tablets, to improve the location system by adding a DGPS receiver, to choose the position of the utility belt or the possibility of running the application in 2 or 3D.

In this project, the external aspect of the device, as well as the prototype of the application has been created. The internal part of the device, which will detect the partial discharge and use algorithms in order to determine how dangerous the situation is, will be provided by Doble engineers, as it goes beyond the boundaries of the project. A marketing and financial plan have been made to support the proposed design.

This project can be seen as a first investigation to recreate a product that meets today's standards, but further investigation is needed in some fields in order to reach the maximum potential of it.

2. BACKGROUND

2.1 Company

The company provider of the project, Doble Engineering, was founded in 1920 by Frank C. Doble in Massachusetts, United States. After graduating, Frank Doble started developing diagnostic test equipment for the electric industry. In those years, this industry was in its early stages, and the equipment developed by Doble helped these companies to better assess their installations, allowing them to know in which condition they were. Thanks to this, electric companies could increase the durability, security and performance of these installations. Since then, Doble has never stopped growing and after almost 100 years of work, nowadays Doble has offices in eleven countries all around the world, more than 400 employees and around 5500 costumers. Today Doble keeps providing electrical industry with better and more sophisticated testing and monitoring instruments for high voltage installations. Doble sells knowledge to its customers next to providing them equipment and services to help them understand what is going on in their substations and installations.

The relationship between Doble and Glasgow Caledonian University started in 2007, developing many innovative monitoring and testing systems that are currently in use all around the world. In 2012, Doble demonstrated their desire to continue working with GCU investigators in order to continue innovating and developing new and more advanced equipment. Moreover, with this agreement, they gave the possibility to future students to continue developing their ideas in such an important company leader of its sector. As Doble's final objective is to make money selling their knowledge, keeping this relationship with the university gives them the opportunity of dealing with new generations of engineers, being able to discover their new ideas and keep evolving and improving their products. This relationship has been going on for many years now, and the good results that Doble has obtained ensure that the relationship will go on for other many years.

2.2 Substation surveillance

Electric companies are using parts of Doble equipment in substation surveillance (Figure 1). Electrical substations are places who are making part of the electricity generation, transmission and distribution system. Due to the high voltage that runs through substations, elements of the substations are under stress, leading to a progressive deterioration with time. The insulators of the equipment are likely to suffer from ageing, and as its function is not only to keep the installations working correctly but also keeping workers safe, it is very important to assess their condition.

Figure 1. View of an electric substation

In a substation people have to deal with very high voltages, which makes it very dangerous and risky to work there. Dangers can be avoided in many ways. Firstly, it is mandatory to use good materials and products. Secondly, the electrical engineers have to work safely in a substation and respect the safety rules. Last but not least, substations have to operate under strict controls.

In order to have the progressive ageing and deterioration of the insulators under control, proactive maintenance is needed. By doing so, electric companies know the condition of their installations and are able to avoid big accidents. If electric companies prefer a reactive maintenance, and they wait till the problem is installed, there is no guarantee that the problem will be detected on time with results in failures in the systems, leading to possible explosions and accidents (Figure 3). These accidents would not only have an immense economic costs but also put human lives in danger. By using a proactive maintenance, they can detect problems at early stages, keeping them under control and solving them before there is any major risk. For example, the results of accidents in transformers, which contain thousands of litres of oil, could be very devastating as shown in Figure 2.

Figure 2. Explosion of a transformer in a substation

Figure 3. Scattered parts after an insulator explosion

Deterioration of the equipment is not only caused by ageing. Other circumstances as environmental stress, poor designs, manufacturing or installation, voids in resins or polymers, bubbles in liquids or oils and many others can accelerate this deterioration. One symptom of this degradation is the partial discharge (PD), which takes place when a system is under high voltage stress and a dielectric breakdown happens. In conclusion, it is important to detect the partial discharge during the proactive maintenance, as it will give information about the condition of the insulators (Figure 4). By observing the evolution of partial discharge, Doble can determine if this deterioration is going worse or if it remains constant and they are able to decide if the installation needs to be repaired or if repairing costs can be avoided for some extra years. Repairing damaged insulators can be costly, therefore electric companies don't want to repair it too early but neither do they want to repair the whole substation which exploded due to the lack of maintenance.

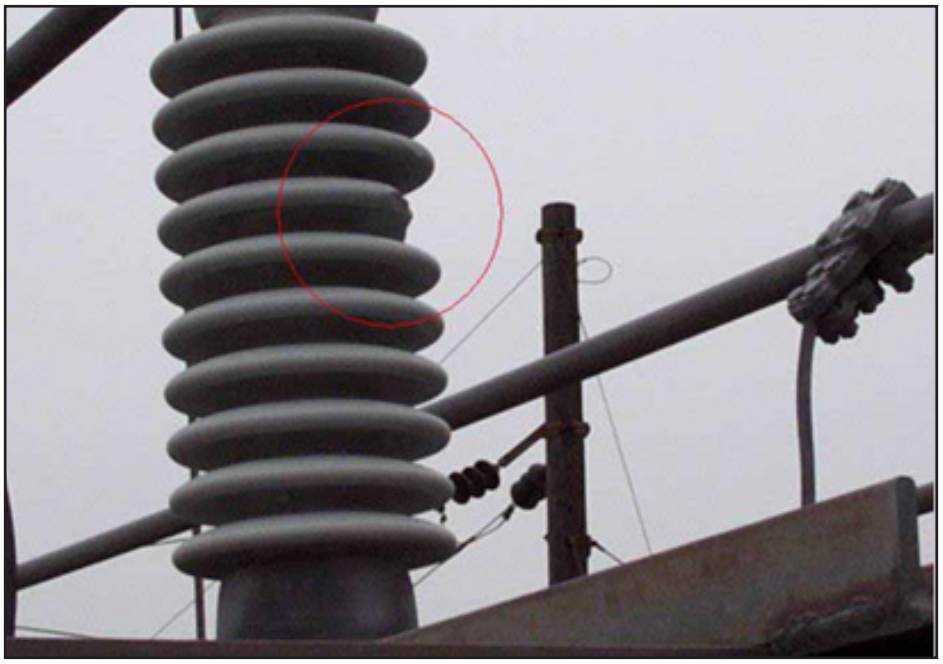

Figure 4. Image of a damaged insulator

When partial discharge takes place, small breakdowns appear in the insulator. The growth of these breakdowns leads into more PD, making the problem bigger with time (Figure 5). When this happens, PD can be detected by many different methods. The spark that takes places produces radio frequency, sound, light, chemical gases, heat and electromagnetic radiation. In this project, the radio frequency that is emitted by the spark is the method used to detect partial discharge using the PDS 100. More information about the radio frequency interference (RFI) can be found in appendix A.

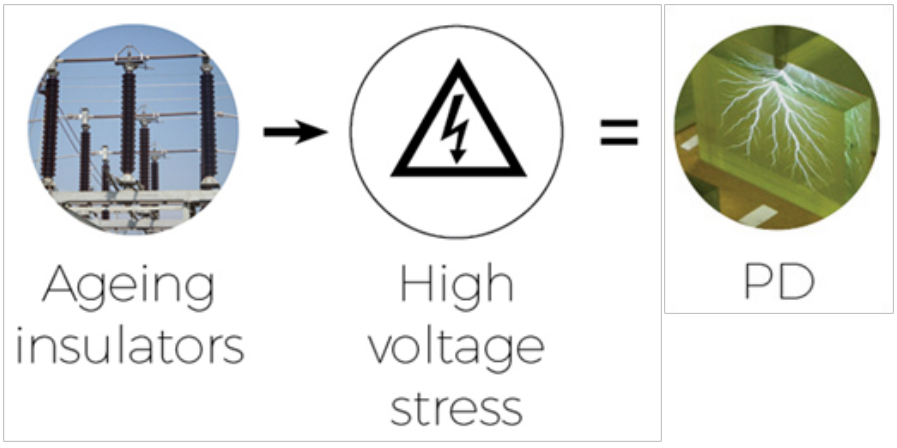

Figure 5. Scheme of the appearance of partial discharge

2.3 PDS 100

The PDS 100 is a surveillance device, designed by Doble engineering (Figure 6), used in electric substations in order to determine the presence of partial discharge. To do so, a electrical engineer walks through the substation and takes measurements with the PDS100. The device actually detects the radio frequency, shown in dB, inside the substation and compares it on the interface with a background measurement that has been taken previously outside the substation. If there is a significant difference between both measurements it means that inside the substation the PDS 100 is detecting the radio frequency produced by the partial discharge. The bigger the significant difference between both signals, the more partial discharge detected. Looking for the points where more radio frequency is detected, the operator can determine where the problem is located. To proceed the analysing and to tell how big the problem is, further investigation is required. These further investigation is done by experted engineers who can distinguish at which level partial discharge is present and how fast it will evolve too something dangerous. Three different levels of partial discharge can be distinguished. The first level would be a first alert to show partial discharge is present. It would occur if the difference between the background and the measurement are around three dB. These level is given the colour green and can be seen as a first alarm. The second level would be amber and would occur when the difference between the background and the measurements would be around ten dB. The last level (red) would occur at a difference of twenty dB and can be seen as the alarm bell to repair the elements where the partial discharge occurs. A lot of other parameters, like the time where changes between measurements happens or comparisons are also used to determine the severity of the problem.

Figure 6. Operator using the PDS 100

Today, Doble is one of the leading companies in detecting PD. The PDS 100 is very reliable, accurate and good working and therefore very successful (Figure 7). Although the product sells very well, some innovation is required. The PDS100 was designed some years ago and therefore it does not take advantage of the disruptive technologies and other opportunities that have appeared since then. Including new features into the device using these updated opportunities could improve the product on user-level and could make human interaction possible. Next to that, new features like a mapping system, the planning of the route and the past measurement points could improve the intuitiveness and the usability of the product. By redesigning the product and trying to include new technologies, Doble aims to preserve the leadership in the sector with a new innovative and interactive product, maintaining the success and reliability of its predecessor. The datasheet of the PDS 100 can be consulted in appendix B.

Figure 7. The PDS100

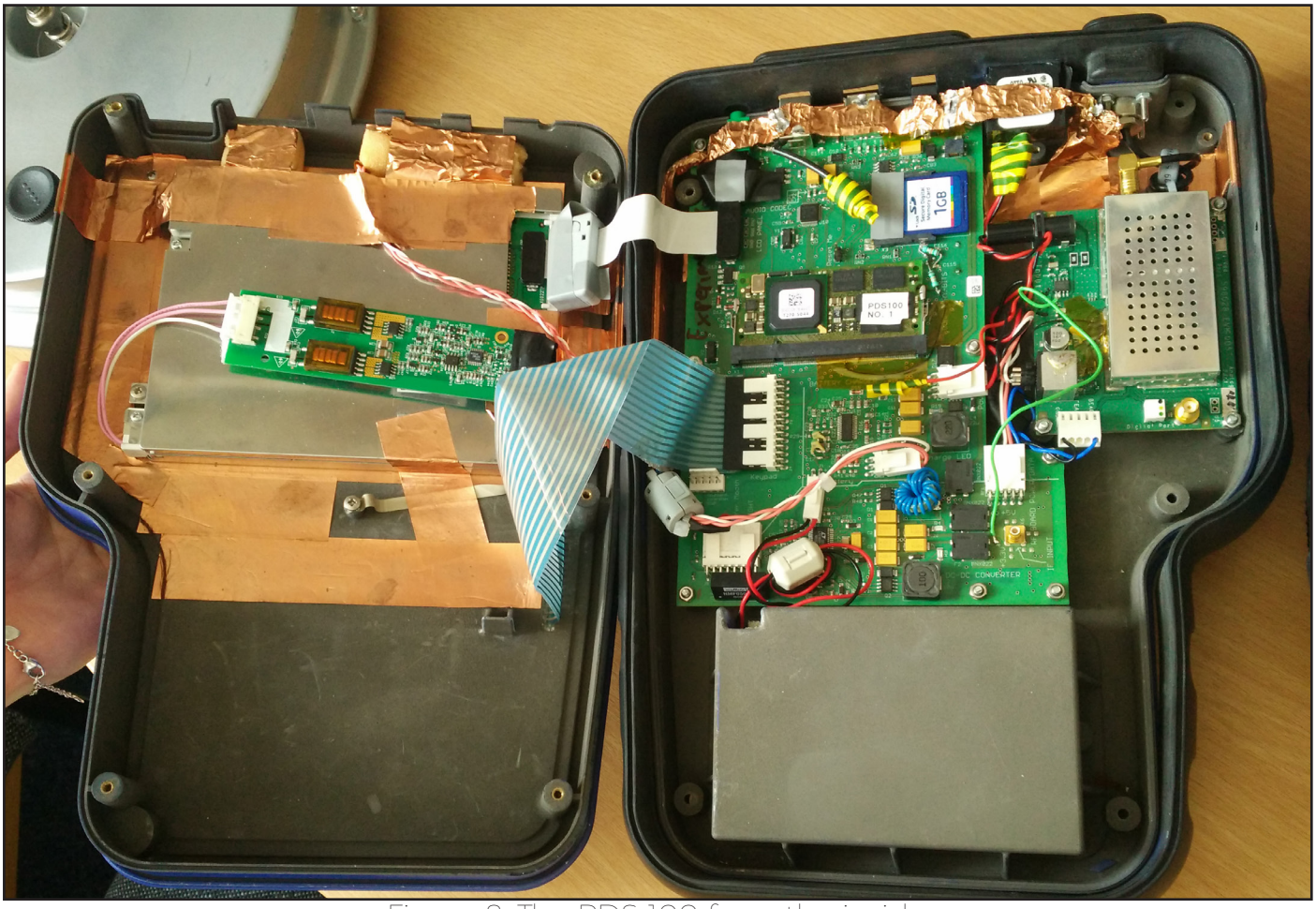

Figure 8. The PDS 100 from the inside

3. PROBLEM/OPPORTUNITY

The PDS100 is of utmost importance in the world of substations and is therefore a best seller in terms of testing instrument for PD. Detecting partial discharge is next to a matter of money, also a matter of life and dead, therefore it is very important that the product is very accurate, safe and good working. Doble puts a lot of attention on this points and easily reached these values on a high level. The product has been designed around ten years ago, therefore it could be improved with the usage of disruptive technologies. Although the product works very well and has a good impact in the market, this new technologies could create a lot of new opportunities and the product could be used more intuitively under today's standards. Next to that, the society has changed to a user-experience society. The user has to enjoy the interaction and find the product exciting, otherwise they will look for other products. These reasons are the main motivation to innovate the PDS100 to a more user-friendly product with an exciting interaction. The challenge of making the product more user-friendly and exciting can be divided into three different levels. The product itself, the way of using the product and the method of collecting data and showing results. For the first level, the product itself, there are many problems that are concentrated around the design of the product. Below is a summary of problems with the product.

1. The product can be heavy to carry for a long time around the substation.
2. It can be difficult to interact with the product due to its size. Both hands are needed for caring the product. This could form a problem to interact with the buttons on the product.
3. The product is suited for right-handed people, but not for left-handed.
4. The antenna is not very practical.
5. The buttons are not intuitive anymore for today's standards.
6. The product is outdated, that means that even if it works well it does not include new technologies that were not available 5 or 7 years ago.

The second level is where a lot of problems can be found in the way that the product is used. Again, a lot of improvements are possible by including disruptive technologies into the new version of the product. Three problems about how the product is used are summarised.

1. The antenna cannot be touched or the product will not work.
2. The antenna needs to be aimed in the correct direction otherwise the product will not work.
3. The user needs to walk around the substation and this can be time consuming.
4. The buttons are useful, but the interaction with the device could be improved.

The last level is about collecting data and showing results. This level could also be described as the user interface. Six sub-problems could be distinguished in this level.

1. The graph that shows the radio frequency spectrum takes a long period to upload.
2. The route that the user takes is not shown on the product, so the user has to carry a map and a pencil for writing it down manually.
3. The results of different measurements from radio frequency tests can't be shown together and compared, so they need to be memorized and checked manually.
4. The program is not suitable for unskilled users.
5. The interface could be more interactive and give an experience to the user.
6. The device does not create a map of the substation with the measurements taken.

4. PROJECT GOALS & OBJECTIVES

The main goal of the project is to provide an innovated product by using disruptive technologies and opportunities and in that way designing a solution that improves on the PDS100 in the following areas:

- User interface
- Ergonomics
- Product interaction
- Data management (Saving, showing & comparing results)

To conclude, the main goal is to make an interactive, intuitive and high tech product by using new disruptive technologies. The design challenge has been written down in a design tool (Figure 9). This includes the requirements on different levels, a bigger picture of the user and the main activity, and the main goal.

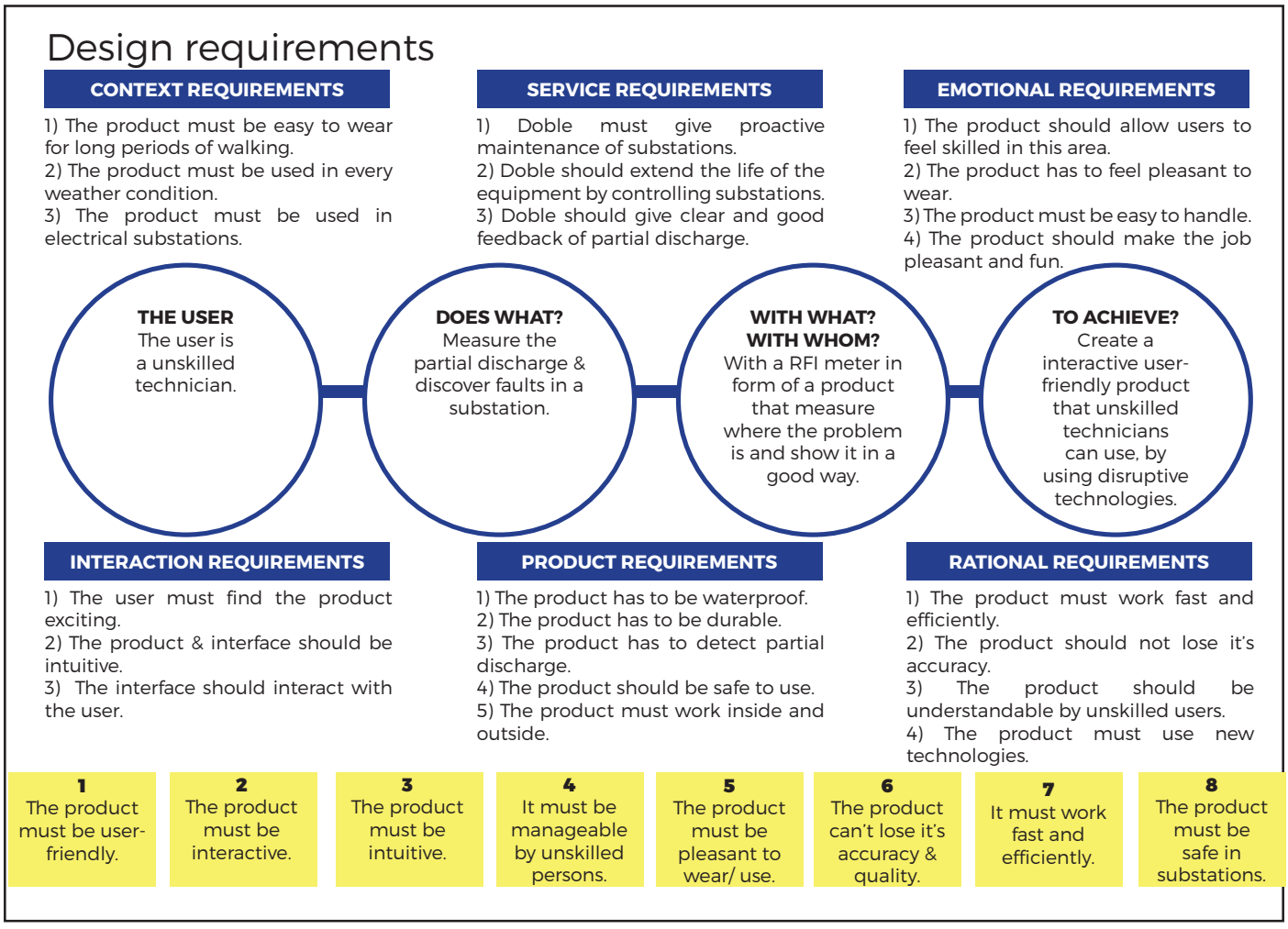

Figure 9. Design requirements

The solution will take new opportunities into consideration next to a market research, any potential risks, legal and ethical values and sustainability. A financial report will identify the cost to put the solution into production.

5. IDEATION

The challenge for the team is making an upgrade of the Doble PDS100, without losing its existing accuracy and quality. Therefore a planning of the design process and a lot of research and brainstorming were needed. In this paragraph undertaken steps are described.

5.1 Planning

The project has been fulfilled during fourteen weeks. In appendix a time-line of the project is added (Appendix C). The project can be divided into three parts. The first part can be described as the analysing part. In these four first weeks the company, the product, the user, the competitors and the problems were analysed and defined. In Figure 10 a short analyse of the user is visualized.

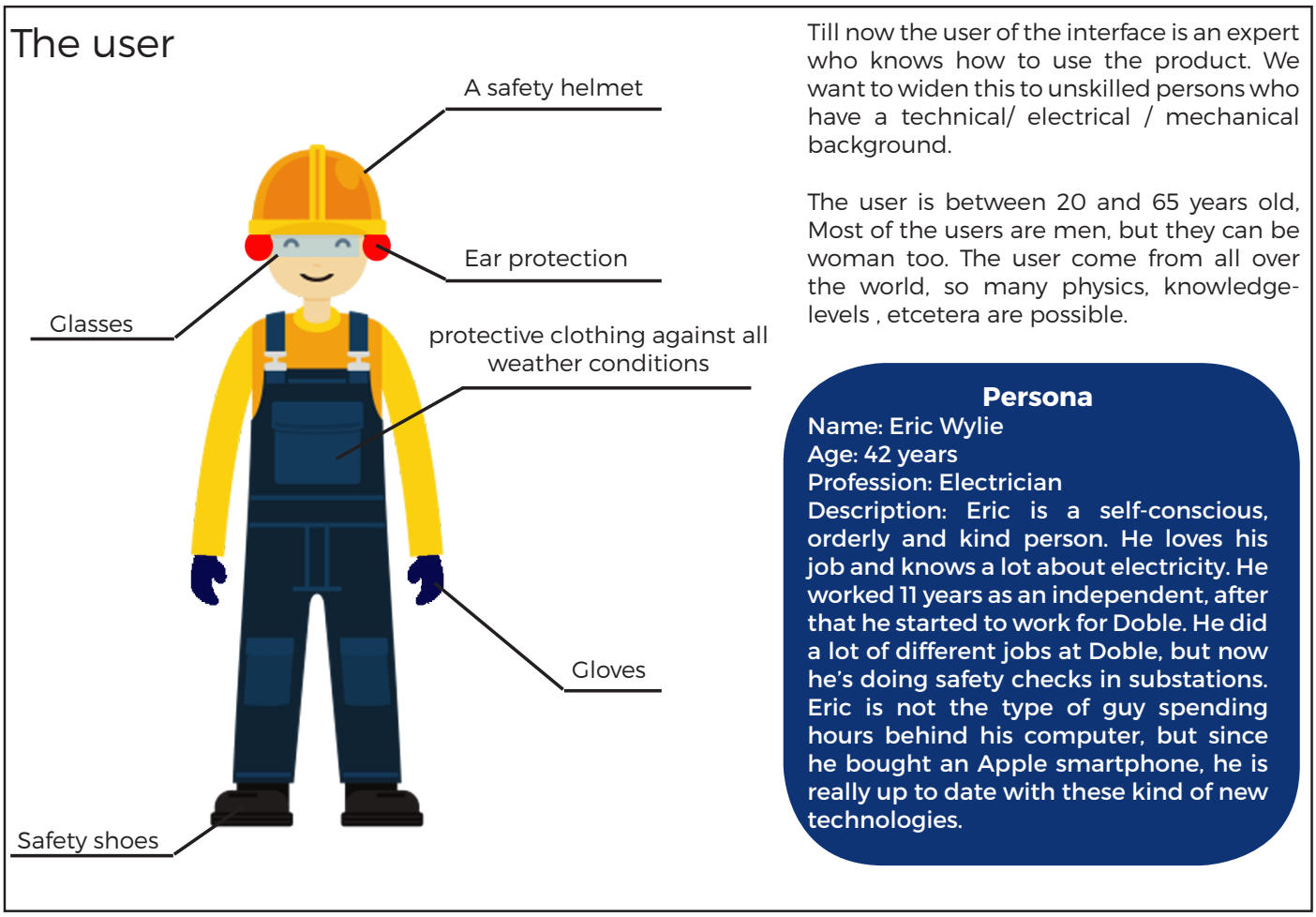

Figure 10. Visualization of the user

The analysis of the problem aloud the ideation process to begin, which aloud the team to find multiple sub-solutions to the problem. In paragraph 5.4 some of these sub-solutions/ concepts and the way these concepts were find are described. A main tool used to create ideas was the brainstorm session (Figure 11).

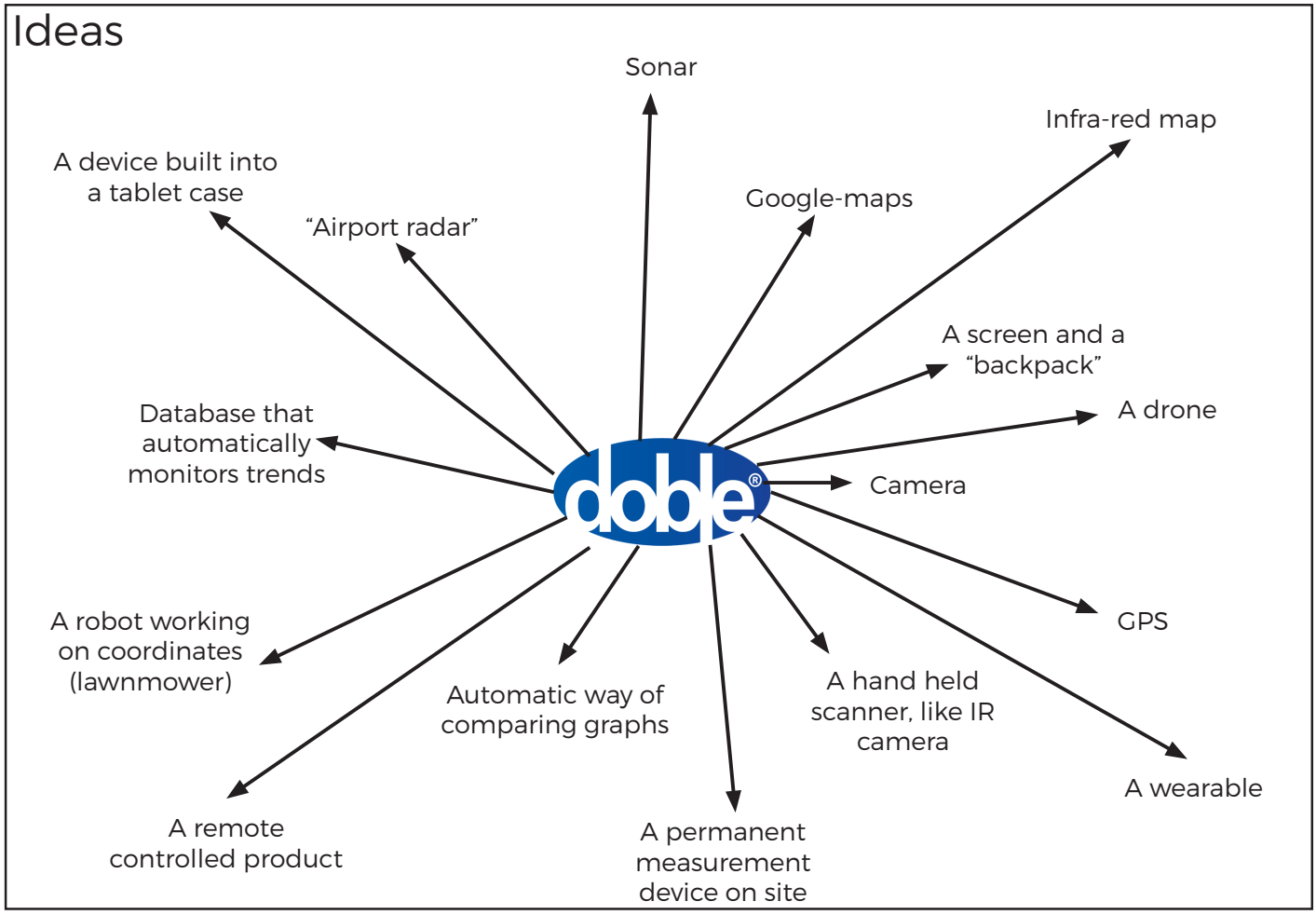

Figure 11. One of the first brainstorm sessions

In the last eight weeks of the project the team focused on the elaboration of the project. A prototype of the interface was made (Figure 12). Materials, the manufacturing, the design and other specifications were defined and visualized. In section 7 a detailed description has been made with the final result of the updated PDS100.

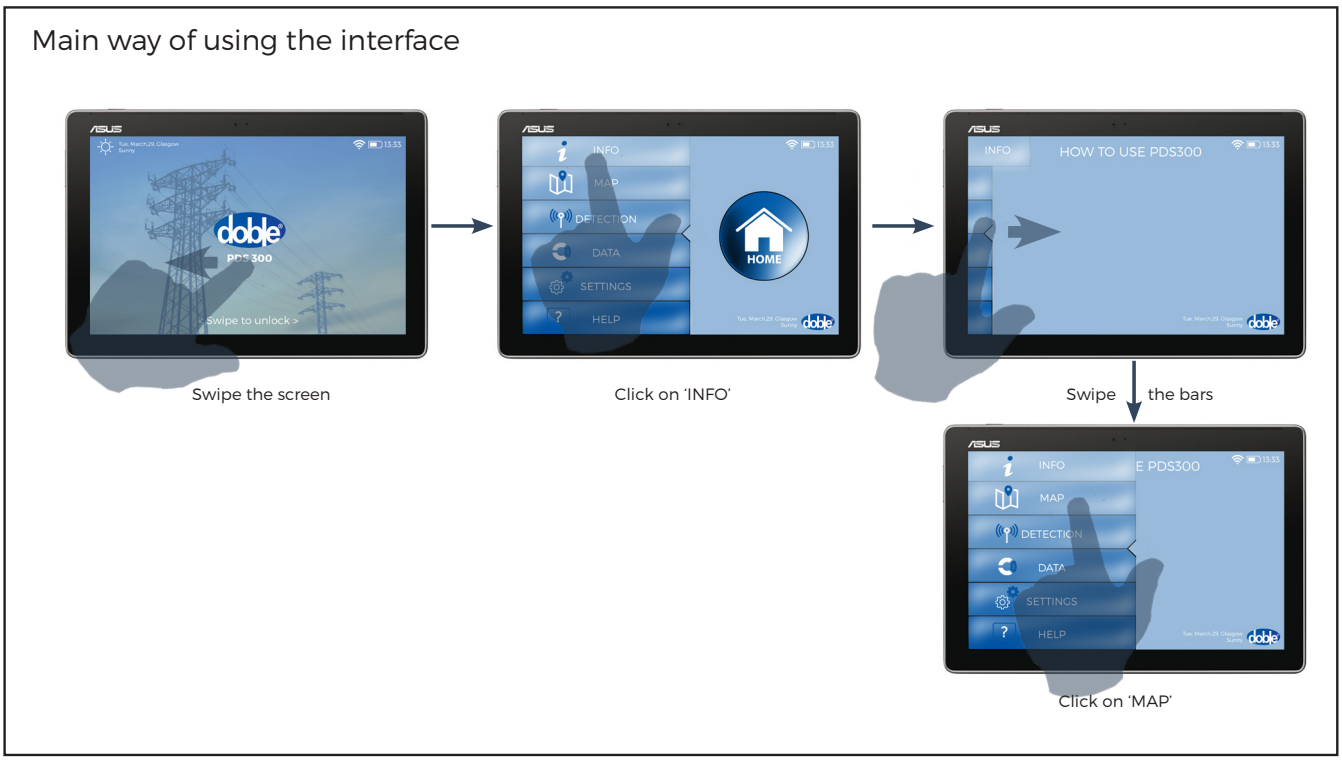

Figure 12. Prototyping the interface

5.2 Competitors

To help find a solution to the problem and aid the idea generation, similar products from different manufacturers will be reviewed to pinpoint different solutions that may possibly be improved in terms of technology, user interface, portability, connectivity and features. (Table 1). Full details of each competitor can be viewed in section D of the appendix.

Competitor	Description	Key features/ideas gained from competitor
HVPD PDS Insight	The PDS Insight is a portable handheld PD detector that utilises 3 different PD sensors (TEV, AA and HFCT). The data is shown on a colour touchscreen on the handheld unit that is controlled using buttons. Further analysis can be done using a tablet running a specialised android app, with the data transferred by Bluetooth.	·Insight uses a barcode reader, with barcodes placed on each asset, for location management ·Use of wireless communications ·Use of up to date technology such as tablet
EA Technology Ultra TEV	The UltraTEV is a portable unit consisting of a large touch-screen interface housed in a body along with the main electrical components. The UltraTEV uses attachments in order to detect PD for different applications using a TEV and ultrasonic sensors.	·Modern touch-screen interface offers usability ·Practicality, since data gathering and analysis can be done on-site ·Rugged design focusing on longevity
Megger UHF PD	The UHF PD is a handheld unit controlled by a 6-inch touchscreen display or through the use of buttons. The device uses the screen for data analysis, but has internal memory that allows it to be transferred to a PC for further analysis.	·One unit with relatively compact dimensions means it is portable ·User friendly touchscreen interface ·Modern software that can filter out noise signals using a phase resolved display
Qualitrol PDM/GIS monitor	The Qualitrol unit is stored inside its own carrying case that allows it to utilise a 12-inch touchscreen interface. An antenna is attached to the unit to detect PD using UHF (Ultra High Frequency) using advanced software.	·Advanced software that allows it to detect multiple sources of PD simultaneously and log them automatically ·Rugged design ·Up to date user interface

Competitor	Description	Key features/ideas gained from competitor
BAUR PD-SGS	The PD-SGS is a handheld unit that shows PD data in real time, showing the severity of it through a 'traffic light' LED system surrounding the main screen.	·High portability due to simplified functions ·Instant awareness of PD and its strength at a location due to LED lights
Techimp Aquila	The Aquila uses an integrated tablet stored inside an industrial carry case which houses all the components, including a 20-hour battery. The Aquila has high levels of connectivity including Wi-Fi, Bluetooth, USB and fibre optic.	·Up to date touchscreen interface ·Large range of connectivity options make it adaptable ·Software allows for automatic reporting of PD detection
Ndb XDP-2	The XDP-2 is a handheld unit offering real time PD detection via a range of attachments, with the data stored and analysed using a PC.	·Adaptability due to range of attachments ·Simple interface make it easy to understand
Sonotec Sonaphone	The Sonaphone uses a 5 inch TFT display, along with a range of attachments, to detect and analyse PD. The device is waterproof and has internal memory for data storage.	·Up to date touchscreen interface ·Compact size makes it portable ·Rugged design
Sonotec Sonaphone pocket	A simplified version of the Sonaphone, the pocket uses a simpler button/LCD interface that only shows real time data since it has no internal storage.	·Basic design means it is rugged ·Adaptability through a range of accessories
PMDT PDetector	The PDetector is a handheld unit that utilises electromagnetic and acoustic ultrasonic sensor to detect PD. An inbuilt RFID (Radio Frequency Identification) scanner is used for asset location management.	·Asset location using RFID technology ·Simple interface means it is easy to understand for users ·Analysis is done on PC using specialised software

Table 1. Competitors

Lessons learned from competitor analysis

Each competitor has a different solution to the same problem, but strong patterns throughout certain solutions can be distinguished. The main one is the use of a touchscreen interface, with 6 out of 10 of the competitors using a touchscreen to enhance the user experience using up to date technology. The software used in some of the competitors is powerful and can do parts of the analysis automatically without input from the user, further enhancing the user experience. These are key features that could be included in the final solution in order to build on the PDS100's interface and bring it in line with competitors. Portability is also a common pattern across the competitors, with 8 out of 10 being handheld, showing its importance in the market. The PDS100 is already handheld, but the current design can be improved using up to date technology.

5.3 Systems used in other fields

Other research which are an aid for the idea generation process, are systems in other fields. A brief review of detection/location systems in other fields that utilise similar technologies has been done. This will allow the problem to be viewed from a different perspective that could bring to light new ideas.

Wildlife tracking

Scientists and biologists utilise radio technology to find and detect animals in the wild. A battery powered radio transmitter will be attached to the animal that uses VHF (Very High Frequency) radio waves (The Migratory Connectivity Project, 2017). The waves are then detected by antennas, which can then be used to triangulate the animal's position based on the strength of its transmitter. Antenna design can aid this process, such as a tuned loop antenna which can give a basic indication of direction through its design.

Figure 13. An example of a handheld tuned loop antenna designed for tracking fish (Advanced Telemetry Systems, 2017)

There are various techniques that are utilised to track animals. The most basic one is tracking their presence to determine if they are within range. A more complex but more useful technique is taking multiple readings from different locations and using the signal strengths, the position of the animal can be triangulated either by using a map manually or automatically through sophisticated computer software that can be analysed on a mobile phone (The Migratory Connectivity Project, 2017).

Oil/gas pipelines

Oil and gas are valuable assets worldwide and are often transported cross-country via pipelines. These pipelines can travel through remote, difficult to access areas such as mountain ranges and deserts. This means that if a leak occurs on the pipeline, it is imperative to locate and repair it as soon as possible due to environmental and economic reasons.

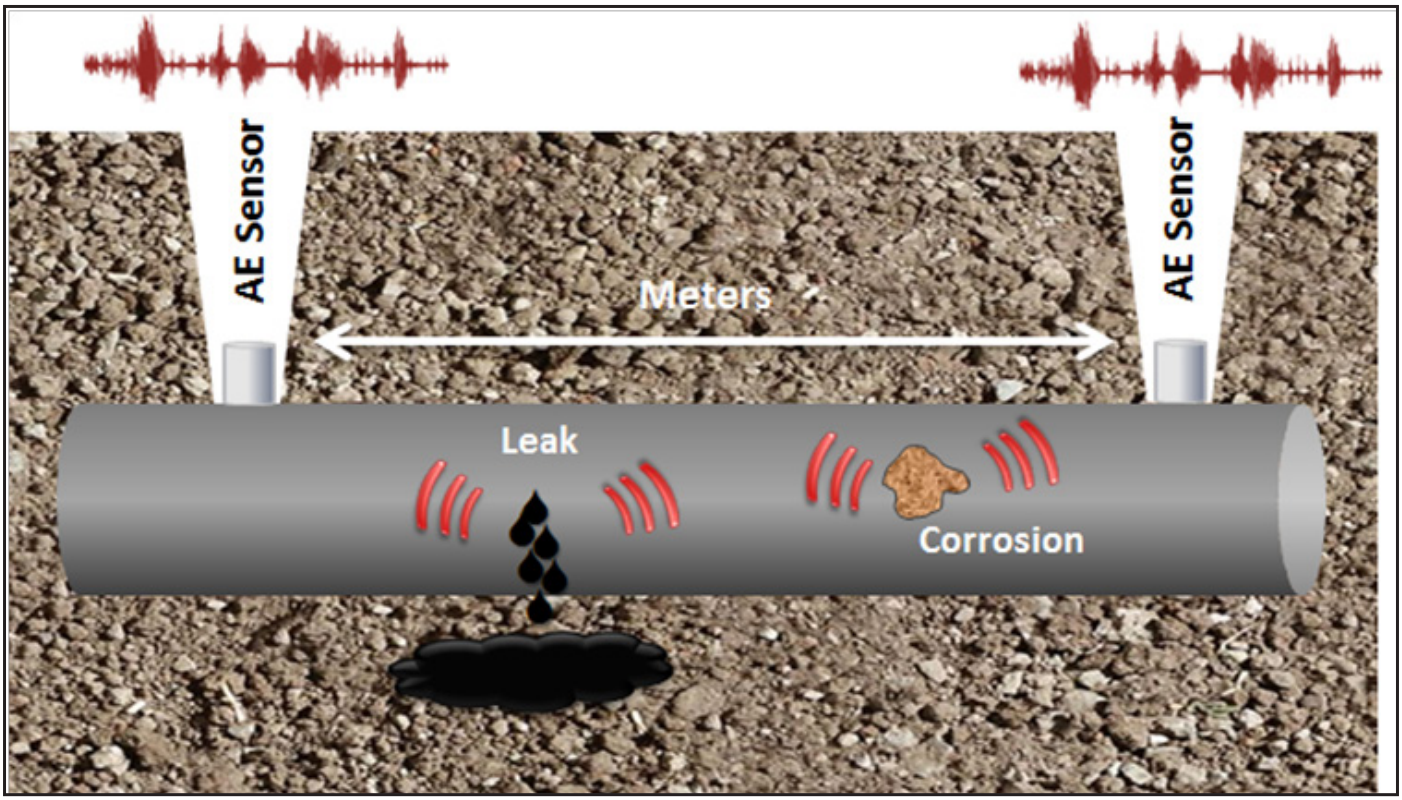

Figure 14. Acoustic detection of leaks/corrosion in an underground pipeline (Idinspections.com, 2017)

A method used to detect leaks in pipelines is by detecting the acoustic signals that are emitted by a leak. This is done by placing acoustic sensors along the pipeline at intervals. This would then create a noise profile (Fiedler, no date). Any abnormal acoustic signals would be clearly visible compared to the background levels. A secondary feature of using acoustic emissions is that fractures and pipeline corrosion can be detected and located with the same method used for leaks (Idinspections.com, 2017).

Lessons learned out of systems in other fields

The main point in both the wildlife tracking and the gas pipeline detection is that the exact location of the asset is given using triangulation, based on signal strength. The acoustic noise profile is a similar idea to the RFI profile that is shown on the PDS100, but the signal strength is used to automatically triangulate and log leaks. The potential of this is that this could be a useful feature in the product, where advanced software could be used to provide automatic triangulation of the PD source from multiple readings, instead of the user having to manually triangulate it, enhancing the overall user experience.

5.4 Idea generation

The idea generation was an important and meaningful part of the design process, therefore a separate paragraph is adequate for this part.

5.4.1 Brainstorming sessions

The wide ideation consisted some large brainstorming sessions on first ideas, disruptive technologies, the user interaction, the packaging, the use and the components and so on. Some of these brainstorm sessions were done with the tutor, others were done only with the team members, but most of them were done by mind-mapping the ideas around clusters (Appendix E). The team gathered the best ideas into concepts. Seven concepts were created with the main ideas under every concept. These concepts were widely visualized and described (Figure 15), a small summary of every concept is to be found in paragraph 5.4.2. (For the full description, see appendix F).

Figure 15. Some of the concepts descriptions

5.4.2 Concepts

Concept 1
Concept one is about using the safety clothes from the user as a tool to attach the product or use them for showing the results. The goggles, the ear protector, the safety helmets, the gloves or even the clothes can be used to attach product parts or be used as a product part itself. The advantage of this is that the technology would be added to something the user already has on, but at the same time, the safety regulations have to be maintained and this can be a challenge for this concept.

Concept 2
Concept two divide the product in different parts. In this concept we divide the heavy components of the product that are needed in two different parts. The components that are mandatory but not used on site and the ones that have to show results or must be used on site. In one of the parts, there will be the battery, the software etc. In the other, or part two, there will be a screen, the antenna etc. With this concept we achieve to divide the weight around the user so that the arms don't feel heavy. The main challenge of this concept is to find a way to connect the different parts.

Concept 3
Concept three is about devices that are placed on site, they could be removable or not. This last one could measure constantly and search for PD. The measurements are done on site, that means they can be done by multiple elements posted on various spots in the field or one big radar. Using this method, the substations would be under permanent surveillance, which would come to the fast identification of problems, but this concept could be very expensive.

Concept 4
Concept four uses remote controlled robots to measure the PD in the substation, that way the user would not have to walk into the station anymore, it could be either a drone or a car, giving preference to the car for safety reasons. Artificial vision can be used as well as a map mode to see where the device is within the substation. This way, the user does not have to walk around the substation and the robot can reach some places the user could not, but the user still needs to be in the area to control the device.

Concept 5
Concept five is about adding components to the product when it is required, to form a modular product. Based on a smartphone or a small tablet where the user can add and remove components as he needs them. Using this method, the product can be lighter and more adaptable to the different user-cases. Also, it would be easier to replace the parts and making them more innovative. However, the components can't be too small, as the user works with gloves.

Concept 6
Concept six is about keeping the main idea of the original product as it works well on its own, but just improve the way it's used and designed. A more ergonomic look and feel, a more interactive user-interface and some extra features could improve the product. It can be questioned if this concept does use all the opportunities that can be found in today's world.

Concept 7

Concept seven is using automated systems to look for PD, that way a user may not be needed all the time. This idea can be separated in two main parts: a car shaped vehicle and a ball-shaped drone, giving preference to the drone as it can go into places a terrestrial vehicle cannot. As the process is completely automated the user only needs to check the data from his device, it can be either a smartphone or a PC, to see if there is any problem and do the appropriate actions if that is the case. However, this concept can be expensive to develop and to obtain a completely automated system may not be possible nowadays.

5.5 Final concept

The final concept is a mix of ideas taken from the concepts developed before. The team made a voting for the best ideas and the more influential ones were concept 1, using safety clothes to attach the product and concept 2, the one dividing the product into two different parts, mainly the idea of using a wearable to show the display and use a backpack to wear the heavy things comfortably. By putting these main ideas together a final concept was developed (Figure 16). This final concept distribute the weight, what makes the long walk through the substation much more comfortable for the user. The forearm is used for the wearable to display the information with either a tablet or a smart-phone. By using the forearm the team is using the opportunity to use a bigger screen, which make it possible to show more interactive information on the interface. The jacket is used to carry all the heavy hardware like the battery, the processor, the camera and so on. It needs to be suitable for every weather condition and meet the characteristics of safety regulations. Next to that the team should take the global market and the purchasers of Doble into consideration. This means that the users, their habits and their safety clothes changes due to the different countries where the system is used. The antenna is the third part of the product, that should be added into the final concept.

The team showed the idea to the company and tutor in order to get feedback. The feedback received from both was really positive, although they showed the team the challenges to overcome in the following steps of the project. The points to work on are the following:

- Looking at a precise positioning and orientation system in every kind of environment, as there are substations underground where GPS does not work and they don't have internet access, that is the worst case possible.
- Security and safety requirements inside the substation.
- Design of an easier way for showing the data to the unskilled user, but also including the old way for a more detailed view.
- A way of wireless connection between the two devices.
- The design of the jacket to be suitable for every weather condition, as substations can be placed either on Africa or Canada.
- Looking specially at one way in which the antenna could send data to the processor.

Figure 16 The final concept

6. CONCEPT DEVELOPMENT

The final concept was approved by the company, but investigation and research is needed for further development of the product. The design, the materialisation and the manufacturing are important points to investigate. Also the connection between both parts of the product and the localisation from the user in the substation need much more investigations and could be seen as bottlenecks of the project.

6.1 Research from design

Both the hardware and the software could be improved. Therefore a first impression of the looks and forms of both were created. The hardware contains the wearable with a screen for the interface, the part to wear the motherboard and the battery, the camera and so on, called the backpack device, and the antenna. The software contains the looks and system of the application.

6.1.1 Product

The product has three significant parts who have to be taken into consideration. The first one is the wearable. The wearable has to be a small tablet or a bigger smartphone that has to suit on the forearm (Figure 17). By putting the wearable on the forearm, the user has more freedom of using both hands and not caring the product all the way down through the substation.

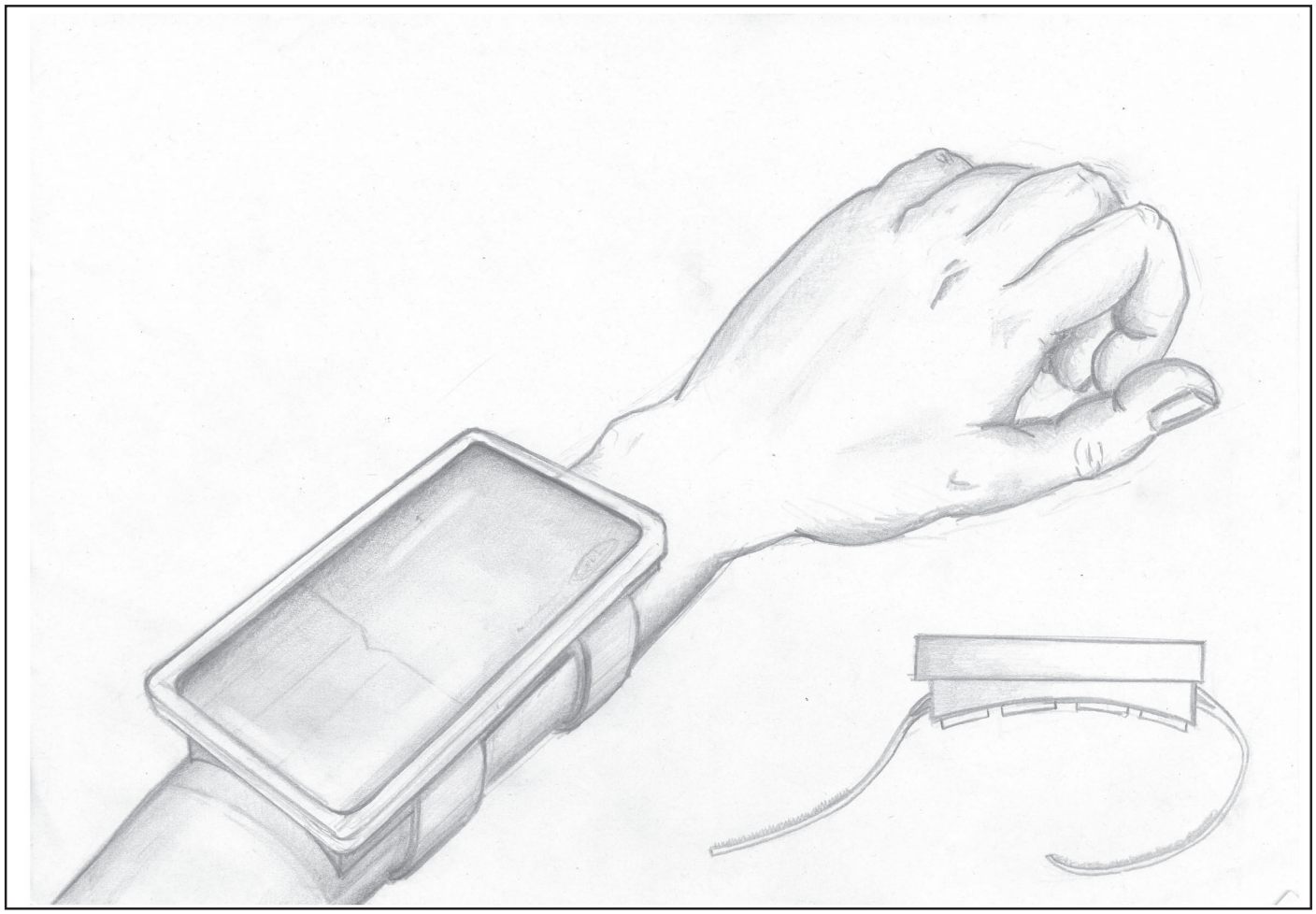

Figure 17. The forearm wearable

The tablet holder

In order to realise the final concept, a device that could hold a tablet would be required. A part of the design process is looking at tablet holders and how tablets are attached to them mechanically. There are two different types of tablet holders, adjustable ones that can accommodate different brands and ones that are designed around a specific model of tablet, such as the example shown below, which has a case designed specifically for an iPad (Figure 18).

Figure 18. iPad holder (Thehumansolutionblog.com, 2012)

The main problem with using this design is that multiple numbers of cases would have to be manufactured to accommodate different sizes/brands of tablets, all of which may become obsolete every few years due to continuing technological advances. This means that it may not be cost effective due to increased manufacturing costs from manufacturing multiple cases and this cost would likely be continuous over the products lifespan. The attractiveness of using an adjustable holder is that only one design is required which can accommodate a large range of phone/tablets, both currently and in the future. The only downside to this method is that not all phones/tablets are currently waterproof, but there is a large array of solutions to this problem from multiple companies, such as the example shown in Figure 19.

Figure 19. Lifeproof waterproof tablet case (Lifeproof.com, 2017) & Armour-X waterproof smartphone case (ARMOR-X LIMITED, 2017)

The advantage of this design means that the user can use their discretion in the choice of device used with the product, be it an industrial tablet, smartphone or a mainstream tablet. There are a large variety of adjustable designs out there, but the most conventional one is one that grips the tablet at its sides and is commonly used for tablet holders in cars, such as the below made by Herbert Richter (Figure 20). This design offers adjustability to accommodate different tablets using a clamp to control width. Another option is the unconventional use of suction pads such as the one from Seasucker (Figure 21).

Figure 20. Herbert Richter iPad2 holder (Holdersandmounts.co.uk, 2017)

Figure 21. Seasucker Naked Flex Mount (SeaSucker, 2017)

This method is useful since no adjustment is needed to fit different sizes of phones/tablets, but the disadvantage of this method is that the device used needs to have a flat back to ensure a strong connection, which is not always possible.

There is also modular systems, such as the one used by snakeclamp (Figure 22), which keeps the tablet clamp separate from the mount/stand through the use of a proprietary interlocking interface between the two parts. This idea could be applied to the final design, but it would be expensive to manufacture multiple sizes of tablet holders to accommodate different sizes.

Figure 22. Snakeclamp tablet holder with interlocking system (SnakeClamp Products, LLC, 2017)

In terms of packaging, since the tablet/phone will be mounted on the user's arm, the packaging needs to be as light and unobtrusive as possible, and the inclusion of an interlocking interface as well as the tablet holder does not achieve this. The suction pads also take up a large amount of space so it was deemed unsuitable for the task.
Therefore the final design would use a similar system to the Herbert Richter holder shown in Figure 20, where the width of the holder is adjustable to accommodate smartphones and smaller tablets.

The backpack device
Another important part of the product is the part to wear the battery, the motherboard, the camera, the antenna etcetera. Different possibilities were taken in consideration. Possibilities like a police-belt or a fisherman backpack were used as inspirations (Figure 23).

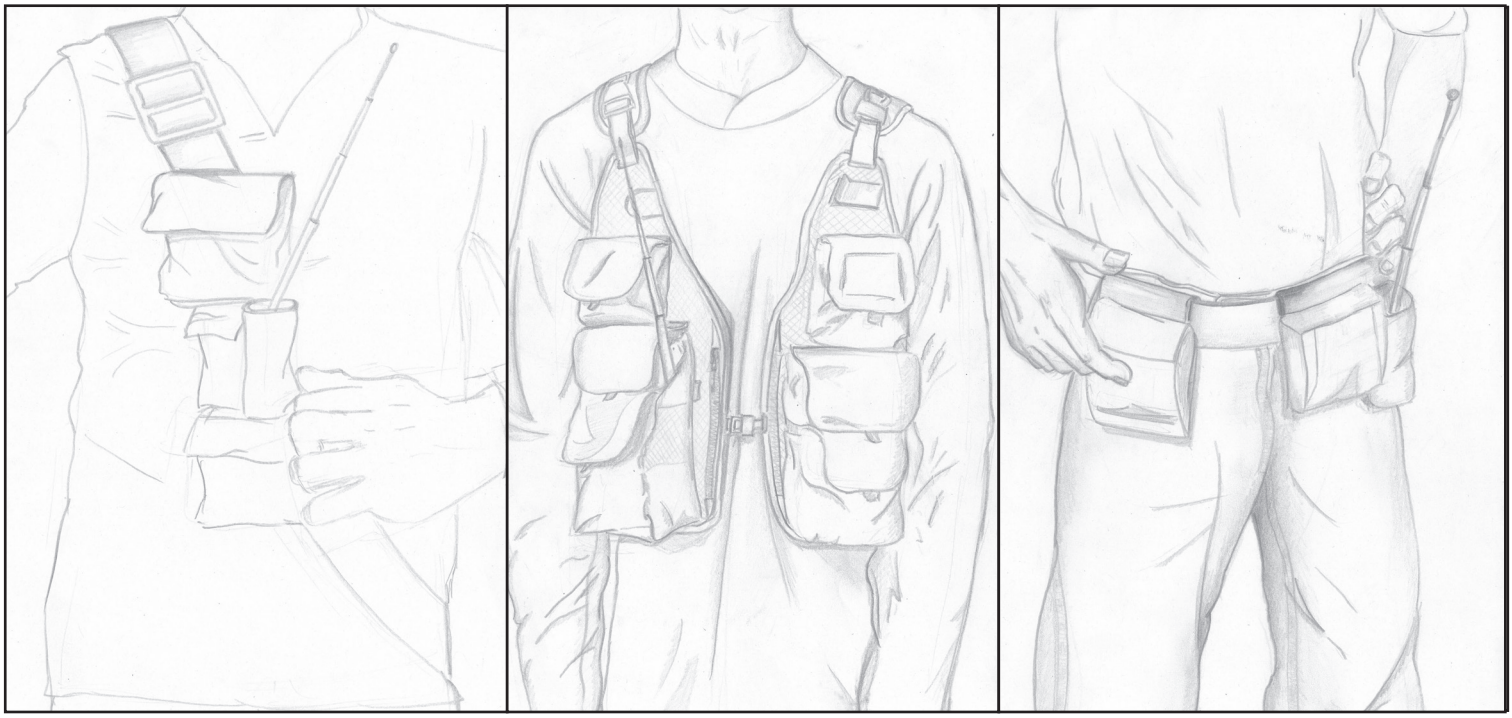

Figure 23. Inspiration for the backpack device

6.1.2 Application

The main software part that has to be designed is the interface. Therefore some research is needed. The application should look fresh and young. Next to that it should interact with the user in an exciting way without losing its intuitively and quality. A first mood-board with existing interfaces (Figure 24) and main colours is used as inspiration. After that a first page of the interface is designed, to create a main look for all the pages (Figure 25). For the steps of the application the team undertook a big brainstorm with the tutor.

Figure 24. Mood-board for inspiration

Figure 25. The main look of the interface

6.2 Systems

A key part of the final product that have not been looked at yet are the specific systems used in the product: the tablet/smart-phone used to run the application, the battery that will be used the run the processor placed in the utility belt and the camera to incorporate the possibility of virtual reality in the product. These are the subjects that will be elaborated in this part of the report.

6.2.1 Tablet / smart-phone

For choosing an adequate tablet or smart-phone for the implementation of the final product, first its requirements should be specified. It has to be taken into consideration that the user is working in a high voltage environment and sometimes in extreme weather conditions.

- The screen needs to be waterproof.
- The tablet / smart-phone has to work with Wi-Fi 802.11 n.
- The tactile screen must work with gloves.
- The duration of its battery should be at least 8 working hours or more.
- The screen is required to fit comfortably on the forearm and at the same time have a big screen for a good view of the map option. Usually the forearm has a length of 24-26 cm, therefore the screen should be around 6'' or 7'' (15,24 or 17,8 cm). If it will be bigger it could become uncomfortable for some users to move the arm.
- Needs to operate in every weather condition, so the range of temperature operation should be around 0 ˚C and 50 ˚C.

Once the requirements are known the research can be started, a comparative table (Table 2) is made for better visualization of the alternatives.

Name	Brand	Screen	Weight	OP Sys	Waterproof	Gloves	Battery	Prices** €
FZ-E1*	Parasonic	5''	426 gr	Windows 8.1	Yes	Yes	14 h	1.304,16
FZ-M1 MK2	Parasonic	7''	540 gr	Windows 8.1	Yes	Unknown	9 h	1.389,05
T800-Ex*	Getac	8.1''	880 gr	Windows 8.1	Yes	Yes	8 h	1.185,50
Gladius 8	Arbor	7,85''	610 gr	Android	Yes	Unknown	10 h	688,33
CT7G	Cedar	7''	590 gr	Android 6.0	Yes	Yes	20 h	825,08
TAB-EX01*	Ecom	8''	1249,9 gr	Android 5.1.1	Unknown	Yes	11 h	1.205,95
RT7	Algiz	7''	650 gr	Android 5.1.1	Yes	Yes	22,2 h	1.054,52
Z710-Ex*	Getac	7''	800 gr	Android 4.1	Yes	Yes	10 h	792,70
FZ-X1*	Panasonic	5''	427 gr	Android 4.2.2	Yes	Yes	14 h	1.236,52
Ulmo	Mitac	7''	580 gr	Android 4.0	Yes	Yes	8 h	389,00
FZ-B2*	Panasonic	7''	540 gr	Android 4.4	Yes	Yes	7 h	849,66
BP50	Pidion	7''	462 gr	Android 4.0	Yes	Yes	12 h	1.037,08
TB100	Unitech	7''	600 gr	Android 3.2	Yes	Yes	6 h	913,18

Table 2. Comparative table of tables/smart-phones

*These products have the certificate Zone 2 of ATEX for being allowed in explosive atmospheres.
**The prices may vary depending on included features, selling companies, warranties or accessories.

It is important to make a distinction between the tablets. Some of them have the ATEX certificate of approvement for Zone 2 and others not.

ATEX is a European legal framework for manufacturers in order to sell equipment intended for use in areas with a potentially explosive atmosphere. The Zone 2 certificate means that the device is able to work in a place with an explosive atmosphere. These places which consists mixtures of air and dangerous substances in the form of gas, vapor or mist are not likely to occur in a normal operation but, if it does occur, will persist for a short period therefore the equipment should be adequate for these events. (Hsegovuk, 2017). This certificate might not be important for some clients, but a must to others, so the solution will be looked up in two different perspectives.

Tablets that have the ATEX certificate:
The one meeting all the requirements is Getac Z710-Ex. Getac is a Worldwide known brand of rugged devices and one of the fastest growing companies in the world, well-known for its innovations, service and support center in the UK. The tablet itself is a good quality device, compact and powerful. It can work with heavy gloves, it's operating conditions are from -20 ˚C to 50 ˚C and can survive a drop from 1,82 m. In addition to that is quite affordable.

Tablets that don't have the ATEX certificate:
The clients in this segment will expect to pay less for not having the certificate from ATEX. For this reason, the final selection here is Mitac Ulmo, an affordable rugged tablet which meets all the specifications. Also it is a light device, which resists a drop from 1 m, has a high-performance and has an operating temperature from -10 ˚C to 50˚C.

6.2.2 Camera

A camera is necessary for having the possibility of virtual reality in the application. As it is needed a frontal view, for seeing the same that the user sees, the camera is included in the utility belt. That said, it is necessary to do a study of the alternatives in order to select the most suitable possibility in the market.

As the camera is an added feature (some users may not want to use virtual reality), it is desired to make it as modular as possible. For that purpose, a wireless camera is wanted, so that the user can place it were where he finds it the most comfortable. The camera sends the data to an Android tablet, where a augmented view is shown on the interface. This assure a enjoyable experience with the device.

Some things to take into account when choosing the camera are:
- Duration of the battery at least 8 hours.
- Suitable for outdoor use.
- Use of Wi-Fi for sending the data.
- Small and compact product.
- A display is not necessary as it is very power consuming and not useful for the user.

After a market research, it was concluded that the duration of the battery for small cameras does not surpass 4 hours in the best case scenario. Different possibilities are discussed, like having spare batteries in the utility belt in order to change them when it is necessary. Nevertheless this solution would be uncomfortable for the user. An acceptable solution would be, as the camera is placed in the utility belt, to have a wire to connect the camera to the external battery if needed. Because of the placement of the wire it will not cause any discomfort to the user.

The options in this section are quite scarce. Outdoor cameras tend to be in two categories: surveillance and action. The surveillance ones are too big to be suitable. The action cameras usually have a display, which is useless in this situation, and usually have bulky waterproof cases.

The third category are the spy cameras. These kind of cameras tend to be very small, wearable and use Wi-Fi for the display of the video. It has features that the user does not need, like the micro or motion detection, but they are the most suitable choice.
Inside the third category, discarding the ones that just record and that are not suitable for outdoor usage. There are two potential solutions:

· PANNOVO Q7S:
A very small and light weigh mini spy camera, with a weight of 16 gr and dimensions of 4,5x2,2x1,5 cm. The video resolution is 1080P. The battery capacity is 200 mAh and lasts for about an hour. The camera supports recording and charging at the same time and can be connected to mobile phone/tablet/PC for time watching videos. The price of this camera is 26,84 €.

· FREDI FR-Q7-01:
Outdoor/Indoor mini camera with Wi-Fi connection to watch the video from the camera in real time. It has a working temperature from -10 ˚C to 55 ˚C. It has also possibilities of short and long range Wi-Fi connection. The price is up to 29,57 €. One problem: there is a huge lack of information about this product specifications.

The product recommendation in this section is PANNOVO Q7S, due to the lack of information of the other option as well as its good resolution, lightness and night vision mode.

6.2.3 Battery

The battery is necessary for running the processor and the antenna, it needs to keep them working for at least as long as the tablet, which means 8 hours of durability or more. In addition, the weight and environmental issues are taken into account in the selection.

Firstly a short comparison of possible rechargeable batteries is done (Table 3).

Type of technology	About	Advantages	Disadvantages
Lithium Ion polymer (Li-ion polymer)	Differs from Li-ion due to the use of a polymer electrolyte.	· Safer then Li-ion · Improved packaging · Lightweight	· Lower energy density compared to Li-ion · Expensive to manufacture
Nickel Metal Hydride (NiMH)	An energy dense, environmentally friendly battery that is used in mobile phones and laptops.	· 30 – 40 percent higher capacity over NiCd · Can be easily transported without breaching regulations	· Poor maintenance can mean poor life after 300 cycles · Performance degrades at high temperatures above 40 · Expensive

Type of technology	About	Advantages	Disadvantages
Nickel Cadmium (NiCd)	NiCd is used where long life, high discharge rate and pricing is important.	· Fast charging · High number of charge/discharge cycles · Strong value for money · Good performance in low temperatures	· Low energy density · Needs recharging after storage · Contains toxic metals that are environmentally unfriendly
Lithium ion (Li-ion)	Used in smart-phones and laptops, Li-ion batteries are lightweight and is the fastest growing battery type in use due to its low maintenance.	· High energy density · Low maintenance · Low self-discharge	· Expensive · Protection circuit required · Heavily regulated for transport due to its fragility

Table 3. Battery technology comparison table (Batteryuniversity.com, 2017)

The most important characteristic to take into account for the battery is that it needs to have a high energy density, as the products needs to be powered for 8 hours. The recommended battery is Lithium ion for its durability, low maintenance, energy density and recycling possibility.

Furthermore, looking at commercial possibilities, it is mandatory to know the specifications for the power supply of the processor, Red Pitaya, and the antenna, so that the battery can actually provide them the necessary energy.

Red Pitaya power supply:
· Voltage: 5 V
· Current: 2 A
· Connector type: micro USB
Camera power supply:
· Connector type: micro USB
· Voltage: 5 V
· Current: Not specified.

The power consumption of Red Pitaya is typically 0.9 A/ 5V, knowing this the capacity of the battery can be calculated. As it has to work for at least 8 hours, the capacity is the following one:

900 mA×8 h= 7.200 mAh

The power consumption of the camera if in 1 hour, it is consumed a battery of 200 mAh, for 8 hours:

8×200=1.600 mAh

Adding both capacities together:

8.800 mAh

The capacity of the battery chosen needs to be 8.800 mAh or more. For giving us a working margin of error of the 10 %, The battery capacity should be 10.000 mAh or more. Also, it needs to have two USB out ports, for charging two devices at the same time.

Name	Capacity	Voltage	Current	2USB	Price
AmazonBasics	10.000 mAh	5 V	2 A	Yes	20,09 €
Aukey Quick Charge	10.000 mAh	5 V	2 A	Yes	20,09 €
Rock Solid	10.000 mAh	5 V	2,1 A	Yes	45,79 €
JeTech	10.000 mAh	5 V	2,1 A	Yes	14,65 €
Lumsig Harmonica	10.400 mAh	5 V	2,1 A	Yes	11,82 €
Mophie Powerstation	10.000 mAh	5 V	2,1 A	Yes	90,68 €
Selectec thin	10.000 mAh	5 V	2,1	Yes	13,71 €

Table 4. Comparison table between external batteries

After the market research, it is recommended to use Lumsig Harmonica because it is the cheapest one providing similar features and giving the product a little bit more capacity than the others. Next to that it has a weight of 40 gr.

6.3 Material selection

The materials that will be used for the design of the final solution will need to meet design requirements due to the conditions that the product will be operating in. A detailed comparison and review of materials with its properties can be seen in section G of the appendix.

Tablet holder

The tablet holder will be exposed to harsh weather conditions as well as the possibility of it being accidentally dropped during its lifespan. There the material should have the following properties:

- High stiffness
- A high rigidity will allow it to hold the tablet more securely.
- High resistance to fracture.
- High resistance to fracture will allow the product to minimise damage from drops.
- High hardness.
- High hardness will allow the product to minimise damage from drops.
- Good finish quality.
- A good finish will give the product a premium, high market look.
- Low-medium density.
- This is for ergonomics, as a low density material will allow the final product to be light and will offer more comfort to the user.
- Sustainable.
- The material needs to be recyclable in order to minimise its footprint on the environment.
- Environmentally friendly.
- The material and its production process should have as low a footprint as possible in order to reduce environmental damage.

Fabric for vest/straps

The material selected for the backpack device is crucial, since this houses the components that does the PD analysis. With this in consideration, a list of desirable qualities can be identified that can be used for the straps for the tablet holder.

• Waterproof.
• In order to protect crucial and fragile electrical components.
• Dustproof.
• Wear/tear resistant.
• Product will be heavily used during its lifetime in harsh conditions.
• Resistance to fading in sunlight.
• Product will spend the majority of its life outdoors, resistance to fading will maintain its appearance and will allow it to maintain its other properties.
• Lightweight.
• For user comfort, a lightweight material will reduce user fatigue over long periods of use.

6.4 Connection

The two units of the product need to have an inbuilt wireless method of data transfer between them so that the necessary data from the PD detection hardware can be visualized on the forearm unit without uncomfortable cables. A basic comparison of wireless technologies will be done, focusing on the following factors: data transfer speed, power consumption and the maximum range of the technology.

Bluetooth
Bluetooth is a common technology used for wireless data transfer and is commonly used for applications such as hands-free phone calls in cars and PC mouse. Bluetooth works by transmitting and receiving radio waves between two or more devices, with the radio waves operating in the 2.4GHz frequency band (Scientific American, 2017). This is also the same frequency band that is used for certain types of WIFI. Like WIFI, there are different types of Bluetooth technology, with the current one being Bluetooth 4.0. Bluetooth 4.0 has a maximum data transfer rate of up to 25Mbps (Paul, 2010). The range of Bluetooth 4.0 is up to 91'44 m (Bennett, 2012). Bluetooth has typically a low power consumption, for sending a data rate of 75 bytes per second it only consumes 2 mW, while Wi-Fi consumes 40 times that power. Bluetooth 5.0 is the new standard, unveiled in December 2016. Designed for the IoT (Internet Of Things), Bluetooth 5.0 has a range four times larger than that of Bluetooth 4.0 and a transfer speed that is twice as fast (Miller, 2016). This means that Bluetooth 5.0 would have a range of 365'76 m and a transfer speed of up to 50Mbps.

NFC
NFC (Near Field Communications), is a short range wireless data transfer method that uses magnetic field induction to transfer data when the two devices are close together or are touching (APC, 2011). The use of NFC is considered to be more secure compared to other wireless standards, but the data transfer rate is slower, at 0.424Mbps (Nosowitz, 2011). It also has a very short range of around 20cm (Hatch | Smart Manufacturing, 2017). Again the short range is a useful security feature but may not be practical for the application in the PD product. An advantage is that using NFC only consumes a small amount of power, around 15mA (Nosowitz, 2011).

Infrared
Infrared is a wireless technology that communicates devices within a short range signal, the range of communication is up to 6 cm, but can be altered up to 15 cm with a special photo-diode. It uses a wavelength of 980 nm, that way the signal is not visible to the human eye. The infrared band of the electromagnet corresponds to 430 THz to 300 GHz, that assures a physical secure data transfer more immune to interferences. There are two kinds of infrared communication.

Point to point: requires a line of sight between the receiver and the transmitter, without any obstacle between them. That provides us with a temporary communication between devices, this feature makes the method unsuitable for the PD application.

Diffuse point: Also called scatter mode, it does not require a line of sight between the devices, for maintaining the link of communication the transmitted signal is reflected or bounced. This is used for example in the wireless LAN.

The data transfer range with new modules can be up to 1Gbps and the power consumption is quite low, for a data transfer rate of 121 bits the system consumes up to 5,844 mW.

Wi-Fi

Wi-Fi (Wireless Fidelity) is a commonly used method of data transfer between devices and for connecting them to the internet. Wi-Fi works by using radio waves, transmitted from a central transmitter to built in receivers in devices, similar to Bluetooth. There are various standards of Wi-Fi:

802.11n
802.11g
802.11ac

The data for each type of Wi-Fi is shown below, in Table 5.

WIFI type	Frequency band	Range	Maximum data transfer speed
802.11 n	2.4 GHz/5 GHz	70 m	500 Mbps
802.11 g	2.4 GHz	40 m	54 Mbps
802.11 ac	5 GHz	70 m	1.33 Gps

Table 5. Data for types of Wi-Fi (Hardesty, 2017), (smallbusiness.chron, 2017)

802.11ac is the most modern Wi-Fi standard out of the three, being introduced in 2012 (Ieee802.org, 2017). Even though that such high data transfer speed is not required for the application and as the application of the standard 802.11 ac is not yet too extended it could be more expensive to implement. The consumption of Wi-Fi compared to the other methods is quite high, for a data transfer of 75 bytes it can consume up to 80 mW.

Li-Fi

Li-Fi (Light Fidelity) provides a method of communication wireless and cheap, it is quite similar to Wi-Fi as they both transmit the data in an electromagnetic way but Li-Fi is a Visible Light Communication system(VLC), that means that while Wi-Fi uses radio waves for the transmission, Li-Fi uses visible light. It has two main components: a LED light bulb (with signal processing technology) where the data is fed into, that sends the data by tiny changes in the rapid dimming of the LED at high speeds to the photo-detector (photodiode) that converts this changes into electrical signals and a signal processing element to convert the data into 'stream-able' content. The LED lightbulb can be dipped and dimmed, up and down at extremely high speeds, that makes it invisible to the human eye. The data transfer rate with this method is around 20 Gbps, the fastest system until now. It transfers the information inside a certain area, right now within a reach of 5 and 10 meters. Also, the power consumption of this system is really low, as LED lightbulbs and photo-diodes are used. Nowadays, the disadvantages of this technology are:

It doesn't work under sunlight.
It requires no obstacle between the receiver and the transmitter.
It is under development.

Comparison

In Table 6 a basic comparison of the systems is done focusing on the data that must be taken into account for the product: the data transfer rate, the power consumption and the range.

Technology	Data Transfer Rate	Power consumption	Range
Bluetooth	25 Mbps	Low	91 m
NFC	0,'424 Mbps	Medium	20 cm
Infrared	1 Gbps	Low	15 cm
802.11 n	500 Mbps	High	70 m
802.11 g	54 Mbps	High	40 m
802.11 ac	1,'33 Gbps	High	70 m
Li-Fi	20 Gbps	Low	10 m

Table 6. Comparison table of wireless systems

The power consumption range is decided comparing to the data included in this report. From the table above (Table 5), the technologies that are not suitable and the ones that are underdevelopment need to be discarded.

- Li-Fi is not suitable as it doesn't work under sunlight and is underdevelopment.
- Infrared requires a line of sight for a temporary connection, as it is needed a permanent one, this system is discarded.
- NFC technology has a range that is too small for the product.
- Wi-Fi 802.11 ac is not an extended standard yet, so it could make the product more expensive. Also, such high data transfer rate is not needed.
- Though Bluetooth 4.0 has a theoretical data transfer rate up to 25 Mbps, but looking at the specifications of wireless adapters using this technology, the actual theoretical maximum data transfer rate is 3 Mbps, which might not be enough for having a fast communication between both devices.

There are two possibilities left for the implementation of the connection of the product: Wi-Fi 802.11 g and n. In Table 7 a research of the commercialized wireless adapters is done taking the price into account. The mother board, Red Pitaya, requires Wi-Fi dongle, also called USB Wi-Fi adapter. For more information about the hardware of the processor go to appendix H.

Name	Brand	System requirements	Data transfer rate	eight	Weight	Price
EW-7811Un	Edimax	Windows XP/Vista/7	150 Mbps		27 gr	7,12 €
TL-WN725N	TP-LINK	Windows 8.1/8/7/ XP/Vista/Linux/Mac	150 Mbps		5 gr	7,91 €
WNA1000M	NETGEAR	Windows 7/8/8.1/Vista	150 Mbps		2,1 gr	9,49 €
DWA-121	D-Link	Windows XP/Vista/7	150 Mbps		27 gr	11,24 €
USB300WN2X2C	StarTech	Windows XP/Vista 7/8/8.1/10	300 Mbps		68 gr	14,27 €
WNA3100M-100PES	NETGEAR	Windows 7/8/XP/Vista	300 Mbps		5 gr	17,75 €
TL-WN823N	Tp-link	Windows 8.1/8/7/ XP/Linux/Mac OS	300 Mbps		136 gr	10,64 €

Table 7. Comparison of wireless adapters

From the table above, the recommended option would be TL-WN725N of the brand tp-link. It uses 802.11 n technology, the data transfer rate is appropriate and it is one of the lightest and cheapest options.

One problem that raised with the connectivity is the possibility of the connection to the cloud and the device at the same time. This connection with two Wi-Fi networks concurrently is possible by creating two threads that run simultaneously.

A thread is the path followed when executing a program. All the programs have at least one main thread, called UI, that runs the interface. Java or Python are multi-threaded applications that allow multiple thread execution at any particular time and running concurrently. These threads are independent of each other and share information among them. An application developer should be able to create an application with two threads, so that the connection of two networks at the same time is possible. Even though that is possible, another solution is to connect at just one thing at a time, either the cloud or the device. Doing that, the user can download the data needed from the cloud from somewhere where he has internet access and, when onsite, connect to the device for receive the processed data. Then, after finishing the surveillance, upload the data when internet is available again. Using this method, the device saves battery, as being connected to two different networks at the same time would require more power than necessary.

6.5 Location

One of the main limitations of the current PDS100, is that it does not include a localization system. The actual method used, in order to know where the measurements have to be done, is to take a paper map of the substation and plan the route that the operator is going to follow and where the surveillance is going to be made. This not only means spending time before doing the surveillance, but also makes it difficult to do the job while using the map manually at the same time. For this reason, making this process automatic would be a major improvement and a key part in our product. The localization system implemented must be able to determine where the user is at every moment during the surveillance, locating him into the substation and indicating where the measurements were made and guiding the operator to these points in order to repeat the analysis in future visits to the substation.

Before starting with the analysis of the available alternatives, it is important to clearly define the characteristics of the method that is going to be used. Doing so, it will be possible to remove some alternatives from the selection:

• Accuracy: Defines de precision with which the technology can determine the position of the user. The accuracy can go from one millimetres to some meters. For our application, a millimetre precision is not needed, but it would be interesting to reach a meter precision.
• Coverage: Indicates the special extension where the technology is guaranteed to work properly. In this case, substations may have several thousand square meters. As substations not always have the same extension, a scalable method could be useful.
• Site of use: Substations can be both outdoors and indoors. In outdoor locations, it is much easier to implement a reliable location system, as the GPS (Global Positioning System) is available worldwide. Indoors, it is not possible to use the GPS and this makes the whole positioning system more complicated because the GPS signals cannot reach those places.
• Price: The more accuracy is needed the higher the price of the product. The accuracy needed has to be evaluated depending on the price that can be payed for it taking into account the final price of the product.

Mautz (2012), compared in his thesis the different indoor location system in use, and represented them into the following graphic (Figure 26) comparing its coverage with the accuracy.

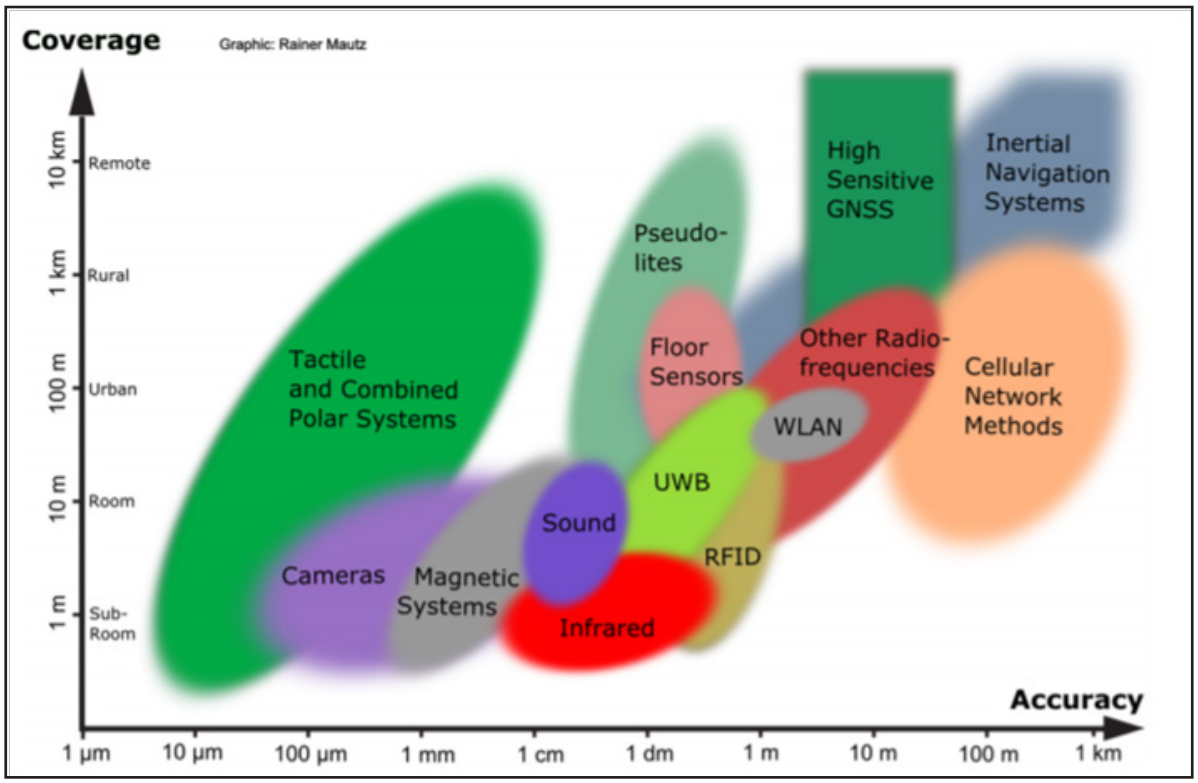

Figure 26. Overview of indoor technologies in dependence on accuracy and coverage

Looking at the graph it is clear that some of the systems are automatically dismissed because they do not meet the accuracy or coverage criteria that is needed. Cameras, infrared, magnetic system, sound, UWB, RFID and cellular networks are automatically not taken into account. The remaining systems will be analysed in order to determine its possible use in the project.

Tactile and combined polar systems

Although the coverage and accuracy of polar systems are great for the project, these methods cannot be applied because of their price. Even the cheaper of these technologies cost around ten thousand euros, making them unavailable for this commercial product. polar systems are based on laser technology, with an array of laser transmitters which is then detected by a receiver, showing its position. These systems have a great accuracy, even of the order of micrometres.

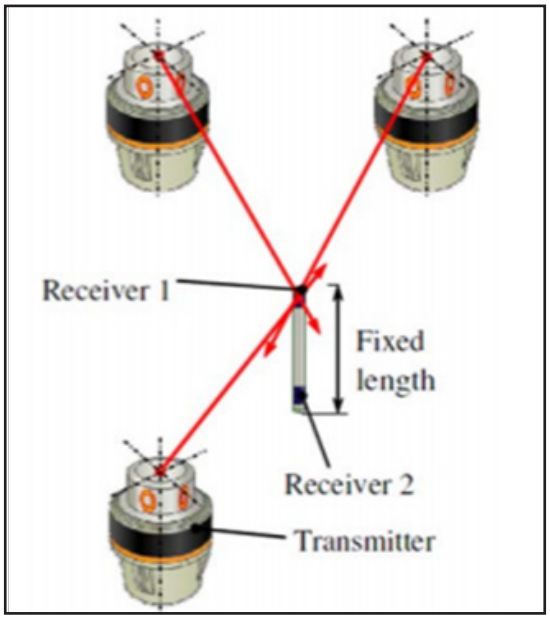

Figure 27. iGPS system from Nikon Metrology, can locate the object with a 0.2mm accuracy and its coverage is 1200 square meters. Its cost is around 60000€.

GNSS / DGNSS

Global Navigation Satellite System has the advantage that it has a world-wide coverage and that more equipment is not needed because it uses the GPS (U.S) / GLONASS (Russia) / GALILEO (Europe) satellite network. GPS chips are widely implemented in all sort of smartphones and tablets, making them cheap and easy to work with. However, these chips cannot guarantee a sub meter level of precision, as most of them can only reach a guaranteed accuracy of around 5-8 metres. In case of indoor locations, this system it is not suitable because the signals from the satellites are unable to reach the user.

Although the typical smartphone GPS chips have this limitation in the accuracy, there are professional GNSS systems used in professional applications that highly improves this precision. However, as GNSS works with receiving the signal from satellites, it is not suitable for indoor applications as its precision will decrease even to a level in which it will not work.

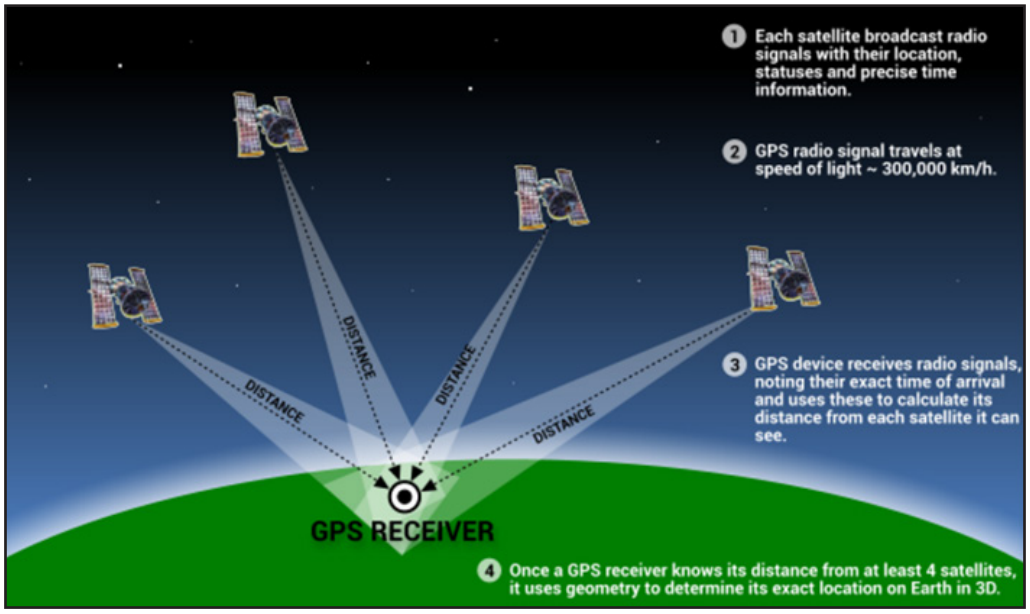

Figure 28. Scheme of the GPS system

As said, the accuracy provided by the GPS systems included in smartphones and tablets is not enough for our purpose. Many other industries such as construction or maritime navigation also need to improve the precision of GPS system, and they manage to do this by using the Differential Global Positioning System. This system improves the precision of GPS by using some reference sites with known position. As these references have a known position is possible to correct the signals from the satellites, being able then to also correct the signal that is being received by the user. By doing that, it is possible to improve the accuracy to a few centimetres if needed. In this project, such precision is not needed, it will be enough with around one meter.

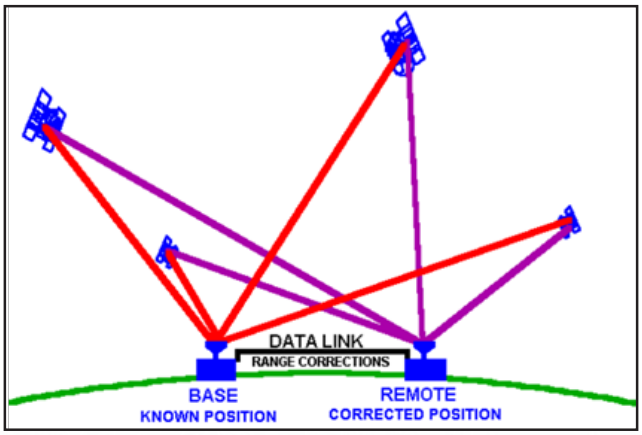

Figure 29. Scheme of the DGPS system

The objective is to find a product with the following characteristics:
- It has to provide and accuracy of at least one meter.
- The product itself has to be small enough to be carried.
- The price has to be adjusted, there are really precise products whose price is too high.

After analysing the market, it has been decided that yhe team will work with a DGNSS of the company Trimble. Doble needs to work with a reliable company, and working with Trimble guarantee good results and no problems, which means that the client will be satisfied with the results. This company has many different positioning services depending on the needed features, which are compared in the appendix I.

By comparing the different alternatives that Trimble offers, the team decide that the Trimble R1 GNSS Receiver is the most suitable product for the project. In the appendix I the datasheet of this product can also be consulted. The R1 is a small device that can be hold in a pocket or in the belt without resulting uncomfortable to the user. It provides a sub-meter accuracy using the differential system provided by Trimble, although the user has to pay a subscription to have access to their reference sites. Another outstanding feature of this device is that is fully compatible with Android, transmitting its position via Bluetooth to the tablet that we are using in our forearm. The battery is another of the key points of this device, as it can last for more than 10 hours, more than enough for a whole journey on substation surveillance. Finally, the device meets all the parameters needed to be used outdoors, as it is waterproof, works in a wide range of temperatures and it is resistant to falls from more than a meter.

Figure 30. User holding the R1 in his left hand and a smartphone in the right one

Inertial Navigation System

Inertial navigation systems use accelerometers and gyroscopes to determine the change of position of the user. If an initial position is known the operator could be tracked while looking at the movements that it is doing. Despite that it seems a suitable solution it has many problems that makes it not possible to be used nowadays, although it could be used in the future if the technology is improved. Unfortunately, accelerometers and gyroscopes are not accurate enough in detecting the distance travelled by the operator.

This accuracy can be improved by using more expensive sensors and placing it in the shoes for example, but there will always be an error. For how this method works, this error will be accumulative, and it will get bigger with time, making it not suitable for our product. Using inertial navigation systems combined with GPS the results are better, as it works as a correction method that increases the precision. However it keeps having an accumulative error which will not made this method suitable.

WLAN and other RF technologies

As seen in Figure 26, the coverage of technologies such as WLAN, Bluetooth, ZigBee or radar are not as extended as needed. To improve the range, the use of beacons could be used. However, even using beacons, for covering a big substation the amount of them that would need to be distributed would be too big to make it viable.

Pseudolites

The word pseudolites comes from “pseudo-satellites”. This system attempts to bring the GNSS system already discussed in this chapter to indoor environments creating a local network. Transmitters produce GNSS-like signals that are detected in the receiver, being able to calculate the position of it. As the signals are much stronger than the WLAN, Bluetooth, etc, less transmitters are needed in order to locate the user in the same space. Moreover, with the scalability of the system, a wide range of spaces can be surveyed, from a small room to a 50-square kilometre extension. The accuracy of the system is better than is needed, by the order of centimetres. This system can be used both outdoors and indoors just by placing enough transmitters depending on the extension of the substation. Another advantage of this system is that as the signals emitted are GNSS-like signals, it would be possible to use the GNSS chip already existent in the tablet, used in the project, as a receiver, without the need of extra equipment.

Pseudolites are the most reliable system that can be used in indoor location nowadays. However, this advanced technology is mostly in study and experimentation phase and the products that are in the market, despite the fact that they work really well and with accuracy, are too expensive for being used in this device. As said, there is plenty of research actually going on in indoor locations based in pseudolites, and it is expected that in a few years there will be more alternatives available with cheaper prices that the ones existing.

Locata, for example, is a pseudolite based technology already in use nowadays that would work perfectly in the project. However, as there are no other alternatives, the price for this technology is not suitable for this application. Locata corporation is an Australian company that started developing this technology in 2003 to solve the problems of location in environments with no GNSS signal available. Locata use synchronized transmitters called LocataLites to send a signal which is captured by the receiver, creating that way a network called LocataNet. With this system, the position of the receiver can be known at a centimetre-level accuracy. This system has been used to cover small spaces like warehouses of 30m x 15m, mines of over 5 kilometres of diameter and even a big extension of 6500 square kilometres in the military field.

As an example of use of this technology, this system was used in 2012 in the Sydney harbour and a precision of 4,4 centimetres was reached. A network of LocataLite transmitters was deployed around the harbour and a receiver was put in every service ship in the harbour in order to precisely locate them inside the harbour zone.

Figure 31. LocataLite situated in the Sydney harbour (up) and Locata receiver in the cabin of a ship (down)

7. RESULTS/PROJECT OUTCOMES

7.1 Final design

Figure 32. Final design

The final design (Figure 32) can be divided into multiple parts and elements, but mainly it consists a forearm wearable with a tablet showing the results on a new designed interface, an adjustable backpack device for wearing smaller elements, like the battery, the camera, the processor etcetera, and the last part is the handheld antenna, which can also be stored in the backpack device, but which is designed to have an comfortable grip when pointing at the insulator. In these section the final product will be described in detail.

7.1.1 Product

The wearable option 1
Option 1 for the design would be a custom made tablet holder that is specifically designed to meet the design requirements of the task. This will be done with the aid of CAD software to visualise the process.

Design process of tablet holder
From the research based on the tablet holder design, it is clear that the design direction is towards an adjustable holder. Therefore the process of creating the final design can be visualised and refined through the use of CAD software, in this case, PTC Creo parametric. The first design (Figure 33) was focussed on the style and proportions aspects. With the use of clamps that would adjust the length, not the width of the holder like the ones reviewed in the research. The side of the device would then be braced against a stopper on one side to keep it aligned.

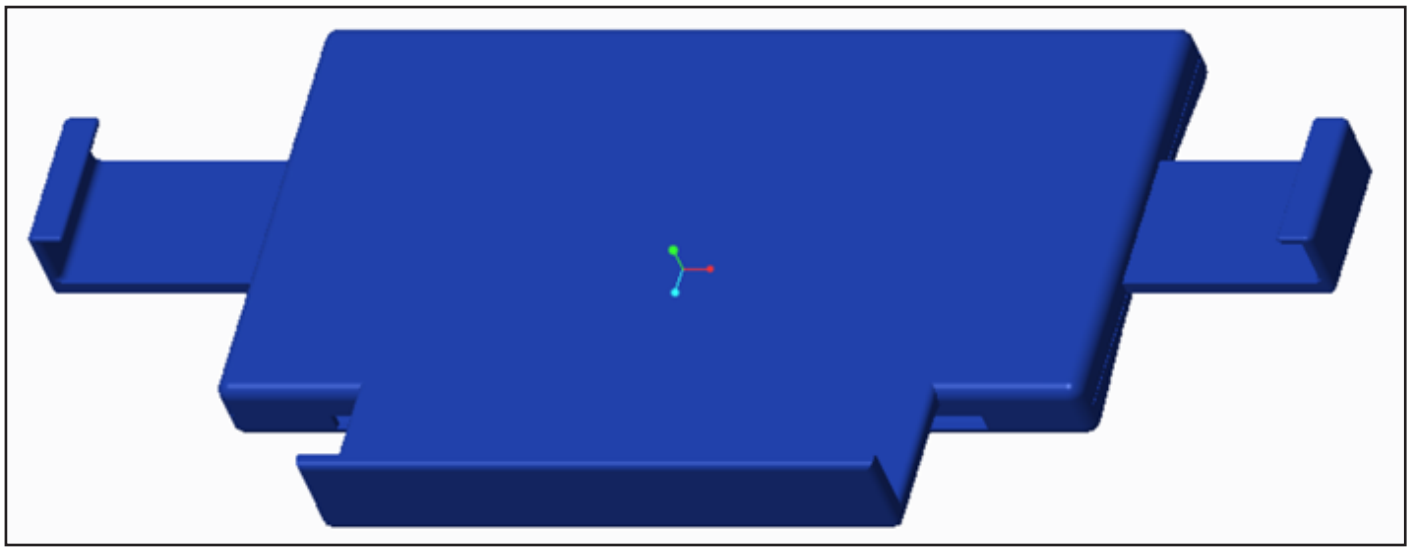

Figure 33. Version 1 of tablet holder

To be able to fit in components inside the casing and to allow it to be manufactured, the casing was split into two halves, with screws used to hold the unit together. In order to follow the contours of the user's forearm, the bottom surface of the casing was given a concave surface that would aid ergonomics (Figure 34) .

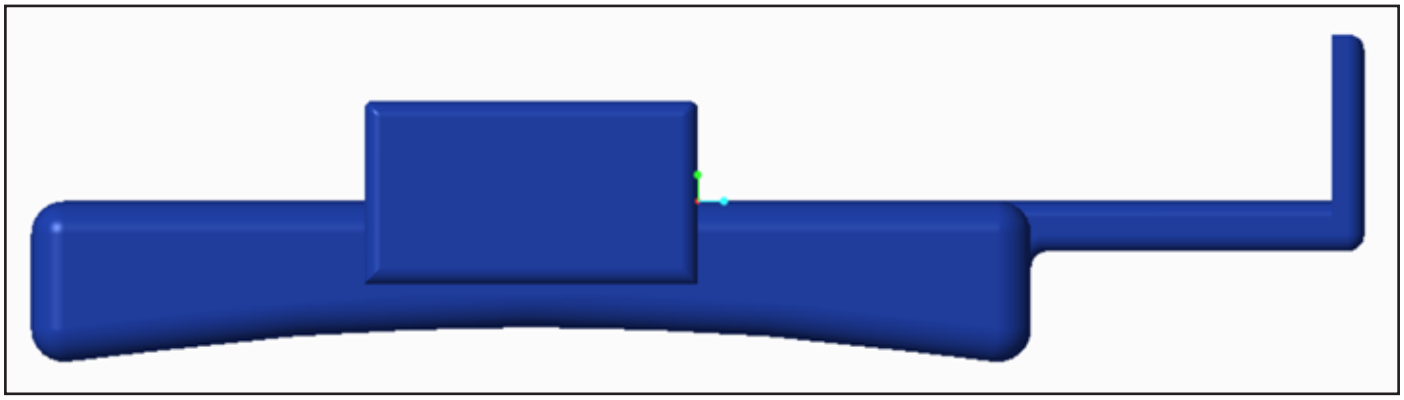

Figure 34. Side elevation showing concave surfacing

The corporate image of Doble was retained in this design by colouring the components in its trademark blue. With further thinking from a manufacturing, mechanical and design perspective, the edges were rounded off to give the product a smooth appearance that would make it more pleasing to use. This also eliminates any sources of mechanical weakness, since sharp edges are a source of weakness.

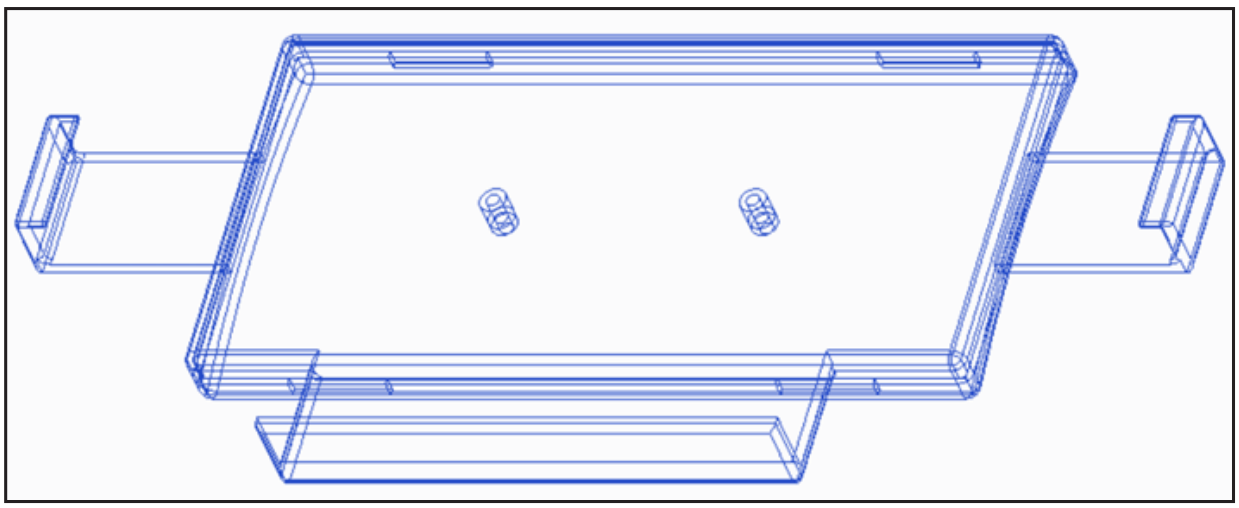

Figure 35. Wireframe model showing internal details

The wireframe model (Figure 35) shows that there is no adjustment mechanism for this model, since it is focussed on design. The wireframe model also reveals the four holes on the sides of the main body which is where the adjustable straps will be attached to. This initial design is a good starting point, but there is room for improvement in terms of the design of the clamping system, with both the side clamps having a small surface area that contacts the device, and the brace using excessive material that means the unit is not as lightweight as it could possibly be. The brace also means that smaller devices will not be centred on the holder and may make it unevenly balanced as a result.

Final tablet holder

Since the majority of problems on the initial design were with the clamping arrangement, this was modified and refined to streamline the final design who would include the mechanism.

The clamping system was rotated to adjust widthways rather than lengthways. This meant that the clamping surfaces could be made much longer, greatly increasing the surface area of the clamps. This eliminated the need for a brace on one side of the holder, reducing overall weight.

In terms of the mechanism, a gear mechanism would be used, with adjustment via an adjustment screw on the outer surface of the product. In terms of gearing, there were two options, a worm gear (Figure 36) or a straight spur gear (Figure 37) , which were both designed.

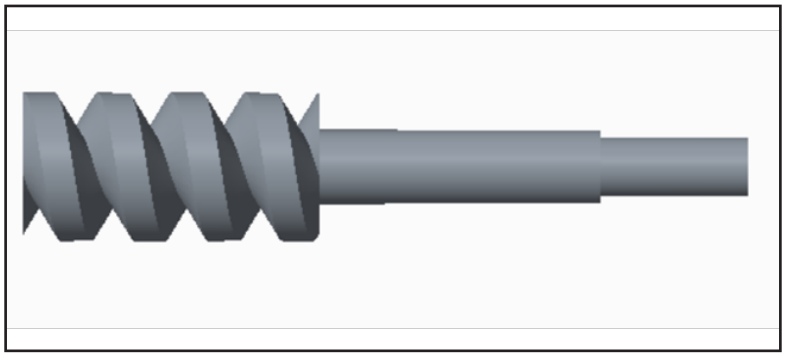

Figure 36. Worm gear

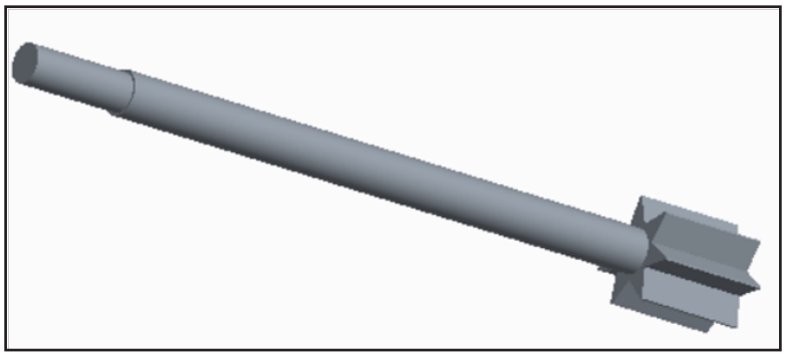

Figure 37. Straight spur gear

For the final design, the spur gear was chosen since it would place the adjustment screw in a suitable position that would offer better packaging and ergonomics. The use of the worm gear would mean that the adjustment screw would be directly under one of the clamps, making it difficult to access.

The gearing was then placed on both of the clamps, with the entire mechanism hidden internally (Figure 38) .

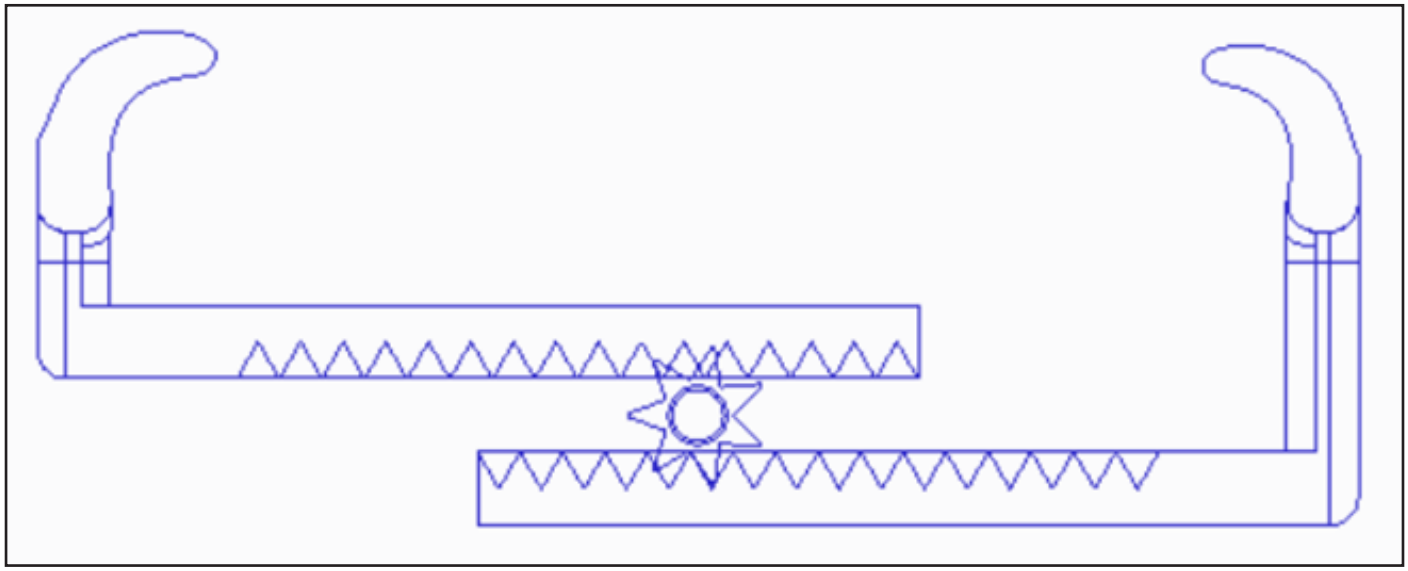

Figure 38. Side elevation of the adjustment mechanism

With the mechanism finalised, other aspects of the holder can be designed around it, with the top and bottom halves having supports that keep the mechanism aligned and have a secondary purpose as strengthening beams to reduce flex in the casing (Figure 39).

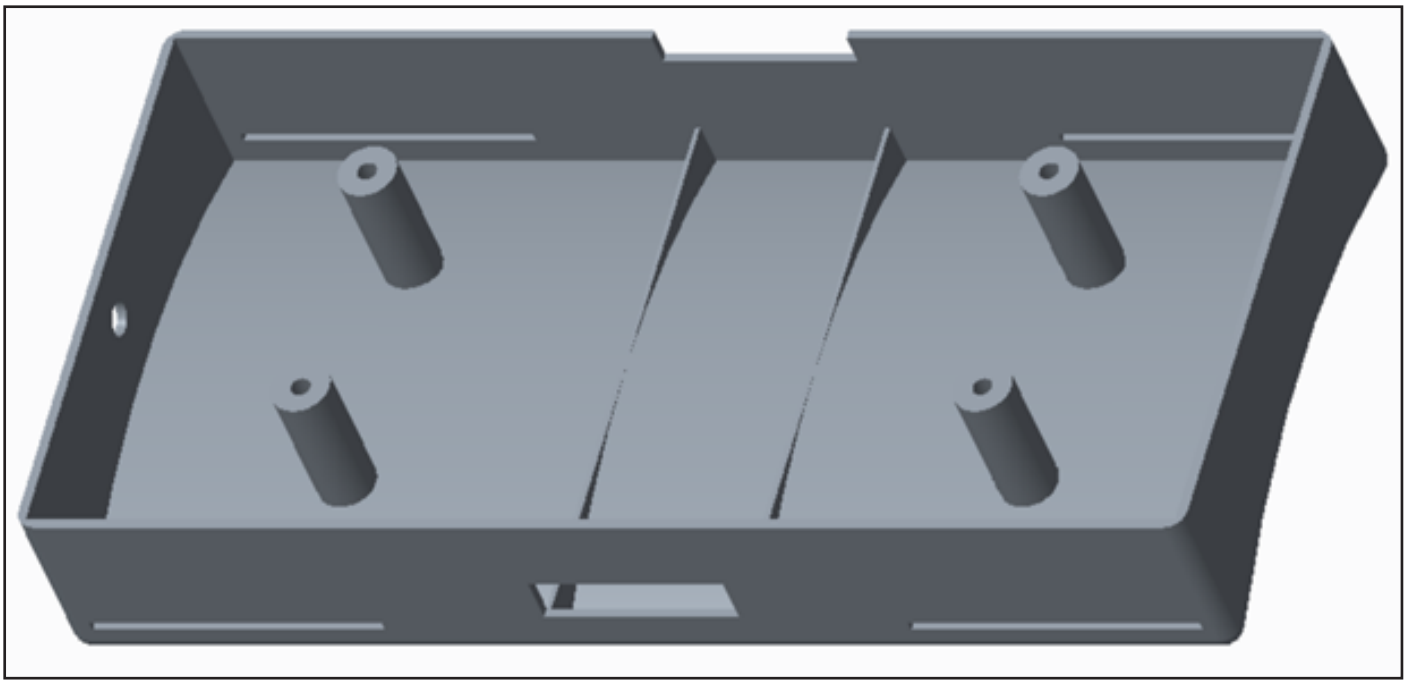

Figure 39 Bottom casing showing screw holes and clamp supports

The number of screws used to join the casing together was increased from 2 to 4 to further boost stiffness. Thin slits were used for the straps.

The design of the clamp was refined from the first design to ensure that it 'hugged' the device through a combination of concave and convex surfacing (Figure 40) .

Figure 40. Side elevation of clamp showing 'hugging' design

Smooth surfacing was used on the majority of surfaces on the holder, apart from the adjustment screw, which was kept rough to allow tactility and grip, especially while wearing gloves.

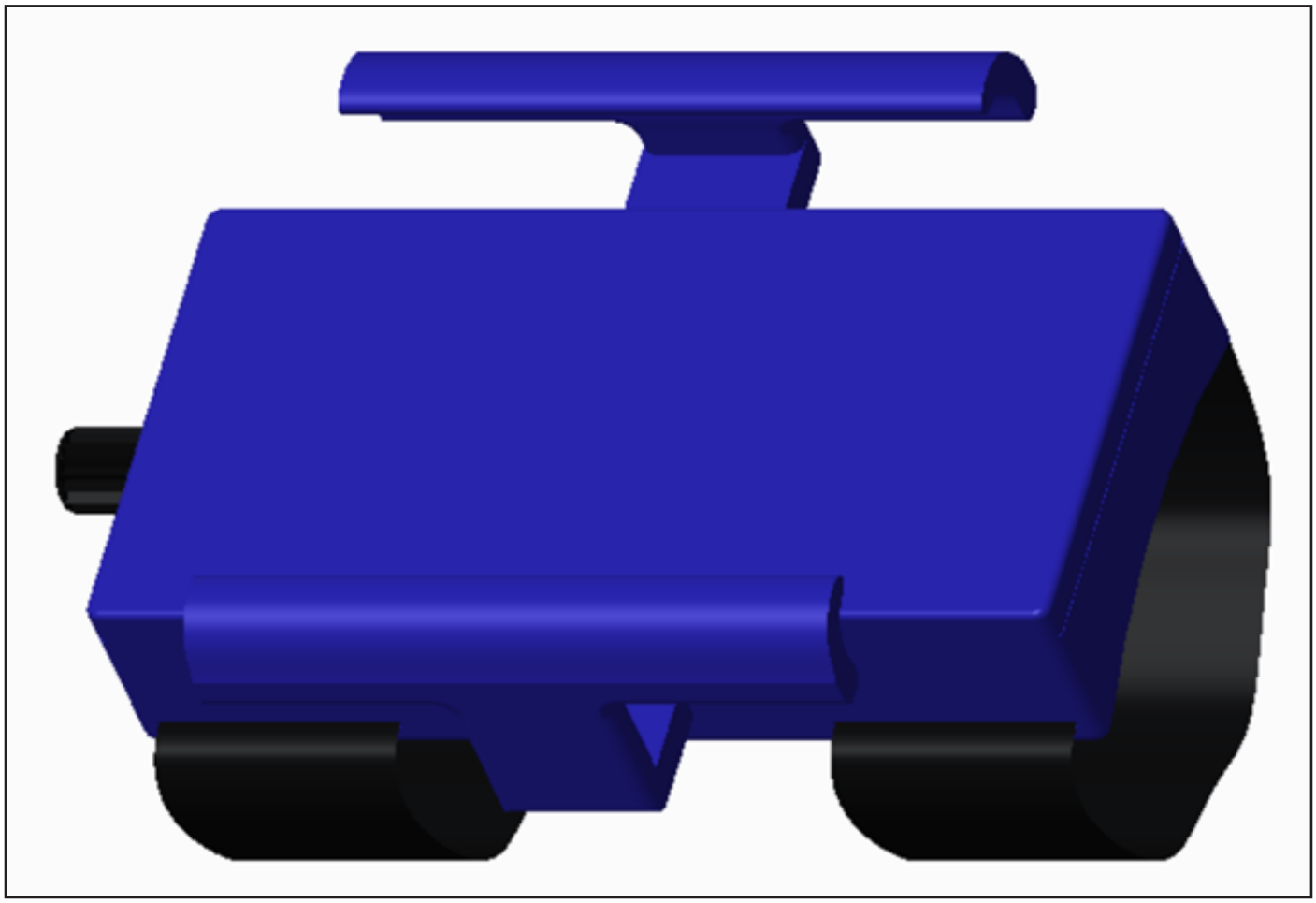

Figure 41. Full assembly of final design

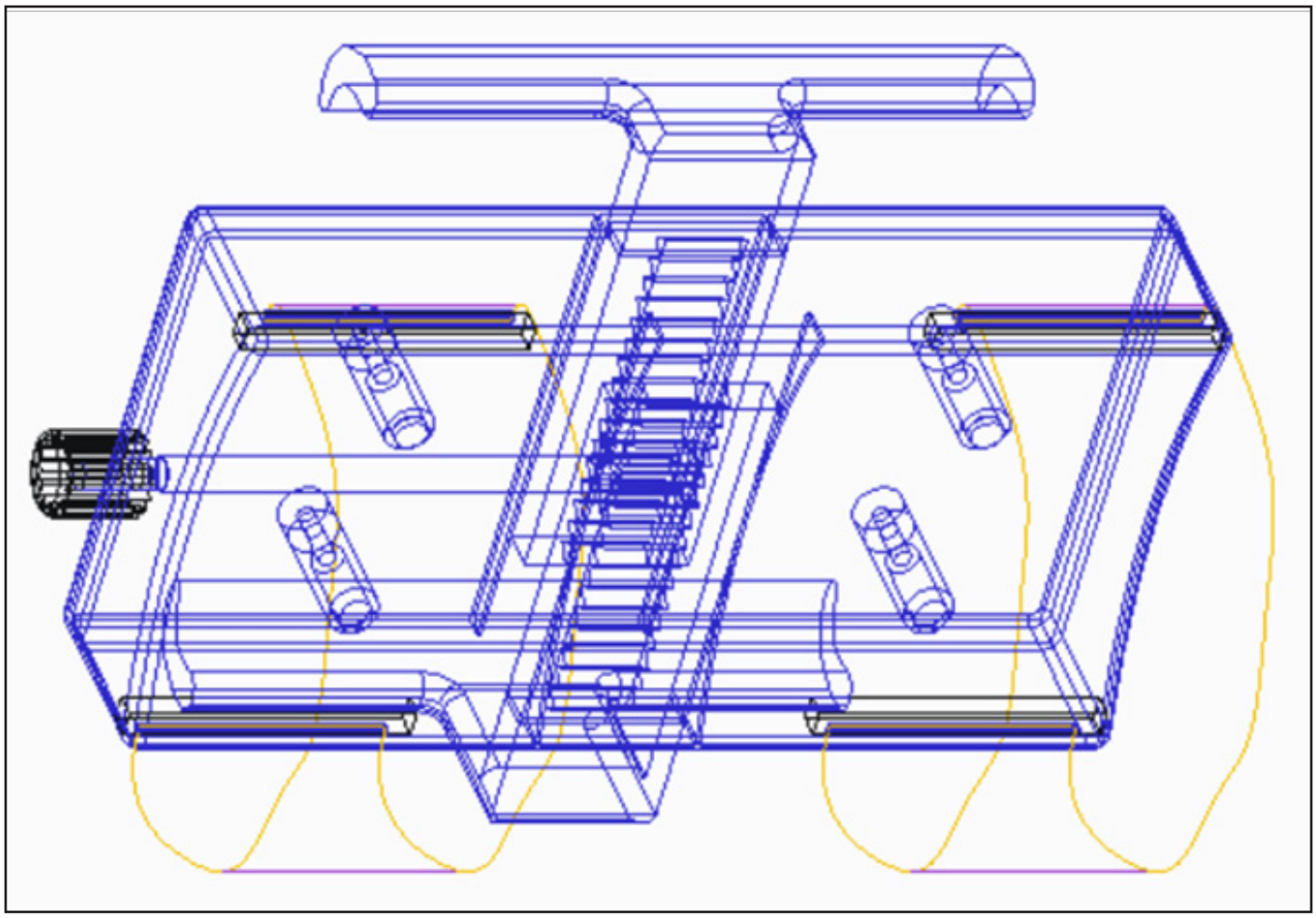

Figure 42. Wireframe of full assembly showing hidden detail

The final design of option 1 has similarities to the initial design in terms of style and surfacing, with a combination of blue and black used to represent Doble's corporate image and raise brand awareness as a result while dramatically improving the clamping mechanism. The full technical drawings for each part can be viewed in section J of the appendix.

The wearable option 2

Option 1 for the design of the tablet holder is a fully custom one that is designed specifically to meet the requirements of the task and is bespoke. But another option could be an 'off the shelf' commercially available option, such as the 4smarts Marathon Universal Sports Armband, as shown in Figure 43.

Figure 43. 4smarts Marathon Universal Sports Armband (Dice.bg, 2017)

The Figure 43 shows a sports armband that is designed specifically to take smartphones from 4 to 5.5 inches using a stretchable holder that can be rotated 180 degrees and can be used for right and left handed users. Sizing is adjusted using a Velcro closure. Key information about the armband can be seen below:

Dimensions:	275 x 128 x 23mm
Weight:	59g
Material:	Lycra
Screen size:	4- 5.5 inch
Cost:	€15

Comparison
The two options need to be reviewed and compared to determine what is the best option by analysing the most important aspects of the products.

• Price
The marathon armband can be purchased for €15 per unit, whereas the estimated cost of the tablet holder is €59.22 per unit, representing almost four times the cost of the arm band.

• Device size
The marathon armband can accommodate smartphones from 4-5.5 inches. Whereas the adjustable design of the tablet holder means it can accommodate a device that has a width from 6cm to approximately 11cm if required, which means it can accommodate most smartphones as well as small tablets and industrial work tablets if required.

• Device protection
The marathon armband offers little protection against damage such as knocks or drops since the device is attached by elasticated cradles. It also offers no device protection against weather conditions. This also applies to the tablet holder, but due to the adjustability of this holder, waterproof cases can be used whereas it may not be possible to use one with the sports armband. Also, the heavier build of the tablet holder and the large surface area of its clamps offer more protection against drops with the high fracture resistance of the ABS plastic it is made from.

• Sustainability and the environment
The tablet holder is manufactured from ABS (Acrylonitrile-Butadiene-Styrene), a thermoplastic that can be easily recycled and can include recycled content in it itself, but is not biodegradable. The sports armband is manufactured from Lycra, which is a flexible polyurethane that is elasticated (Acadex.com, 2017). Polyurethanes are a thermoset plastic and their molecular structure permanently remains in its original state and cannot be modified, meaning that they cannot be recycled. Therefore the tablet holder is the more environmentally friendly option.

• Quality
Since the product is going to be low volume and high value, quality plays a key part since a low-quality product may be unreliable and may not be able to satisfy customer's needs as a result. The tablet holder is a bespoke design and the overall design and production of it can be carefully controlled through close collaboration between Doble and its suppliers, maintaining a high standard of quality. The sports armband is bought directly from the supplier, with no knowledge or control over the manufacturing standards of the product, meaning that quality is an uncertainty. In terms of quality, option one is the better choice.

• Appearance
In terms of the overall appearance, the tablet holder is bulkier than the armband due to its rigid construction, but the design is simplistic, with smooth edges and a smooth finish that makes it appealing. The hardness of the ABS plastic ensures that the finish will be maintained over the products lifespan. The armband is a much more minimalistic design due to its mostly fabric construction and is has a less intrusive appearance. The fabric construction of it may mean that the appearance will get worn and tarnished over time.

Conclusions
The comparison of the two phone/tablet holders has shown that both options are suitable for the task in different ways and both come at a cost. Despite the much higher price, option one is the most suitable due to the following reasons:

• More adaptability in device size and accessories used (waterproof/shockproof cases etc.)
• Better device protection due to more rugged constructions that encloses the device more
• More durability due to being made from rigid ABS plastic instead of flexible Lycra
• More secure clamping system
• Able to be recycled
• Quality of the product can be controlled to a higher standard
• Finish will be harder wearing

These are the key reasons why option one is better than option two, with the only exception being the higher cost. However, due to the market placement of the product (High value, low volume) the increased cost is offset by the larger number of features that may attract more customers and the higher quality meaning that less money will be spent on repairing defective units. Also, the larger range of adjustability allows more options in terms of the electrical devices used, meaning that lower cost options could be sourced compared to devices required for option two.

The wearable Option 3
Option three is also a commercially available option, which is the Sacci Hook shoulder harness (Figure 44) .

Figure 44. Sacci hook harness (ruggedmobilesystems.co.uk, 2016).

This design allows the device to be mounted onto the user's body using a harness, which is said to reduce fatigue and allows hands free usage (Rugged Mobile Systems, 2017). This design can be used with a variety of different brands of tablets such as:

- Motion
- Panasonic
- Xplore
- Trimble
- Getac

These tablets can be used with a custom made holder, suggesting that the harness is not limited to just these brands. The Sacci hook was designed with surveillance and mapping, or any other applications that required long periods of continuous use, making it ideal for a substation environment.

Comparison

In terms of comparison to option 1, there are many details about this harness that is not readily available, such as price and materials, but a comparison can still be done in terms of design and features. Option 2 is ignored since a comparison has already been done, showing option 1 to be the better solution of the two. Both options are highly adjustable and can be used for a wide range of users, but the Sacci may offer better ergonomics since the weight is placed on the body, offering better weight distribution and reducing fatigue. The overall weight of the harness may be higher due to its larger size. Both options are fully adaptable in terms of accommodating different devices, the Sacci by using custom cases and option 1 through an adjustable mechanical design. But the Sacci is designed for tablets and notebooks, whereas option 1 can be used for tablets and smartphones. The Sacci appears to have a strong construction considering the tasks that it is designed for, but the material is unknown and may not be suitable in a substation environment if manufactured from an electrically conductive material. The main downside of the Sacci is that it may not integrate well with the backpack/vest that will house the electrical components, since this is also mounted on the user's body, leaving option 1 as the best solution.

The backpack device

The team is required to search for a suitable utility belt, (backpack device), to carry all the heavy stuff comfortably. First, some characteristics need to be specified.
What does the backpack device need to carry and which are de dimensions of these stuffs:

- Red Pitaya processor with case (see annex X): 10,7 x 6,8 x 3,29 cm
- Battery: 13,8 x 5,9 x 2,1 cm/ 340 gr
- Antenna: length 21,0 cm
- Location receiver (if necessary): 11,2 x 6,8 x 2,6 cm /187 gr

The camera is not included in this enumeration as it's an optional feature and it is really small and light, with his own fixing possibility.

Other characteristics to be taken into account are:
- Waterproof
- Semi rigid

Once a market research is done, a selection of the alternatives is done. Some possibilities for the backpack device are described below.

DYJ Tactical Waist Pack Bag Molle

Figure 45. DYJ Tactical Waist Pack Bag Molle

Adjustable waist strap drop: 71,12- 132,08 cm
Five pockets with different sizes:
- Main compartment: 20,1-32,0 W x 15,0 H x 5,1-144,8 D (cm)
- Back: 24,1 x 11,2 x 1,5 (cm)
- Zipped front: 12,7 H x 12,0 W (cm)
- Two side pockets: 14,0 H x 12,0 W with mesh division

It can be used as waist bag or shoulder bag (Figure 46).

Figure 46. DYJ Tactical Waist Pack Bag Molle in both positions

This device is suitable for outdoors and is waterproof; its outer material is 1000D high-density Oxford nylon.
Weight of 408,2 gr
Price: 18,32 €

The processor and the battery can fit in the main pocket, the location receiver can be added into the strap, and the other pockets would be free for the user's personal stuff.

Pellor Black Utility Tool Pouch Detachable

Figure 47. Pellor Black Utility Tool Pouch Detachable

Adjustable belt with first waist up to 129,54 cm.
Includes main bag, smartphone case, water bottle pouch and 2 accessory pouch, all the pouches are detachable and used separately:
- Main bag: 16 x 20,1 x 9,91 (cm)
- Water pouch: 7,4 x 7,4 x 17,2 (cm)
- Price: 22,03 €

The processor and the antenna can fit into the main bag, then the user can decide to attach or not the other pockets depending on his needs. It can be used as a fanny pack or a small shoulder bag (Figure 48).

Figure 48. Pellor Black Utility Tool Pouch Detachable both possibilities

Wotow Military Single Shoulder Bag

Figure 49. Wotow Military Single Shoulder Bag

Adjustable waist strap fit size from 76,2 - 121,92 (cm)
Pocket size: 24,13 x 7,62 x 14,73 (cm)
It has a basic water bottle holder and a side pocket ideal for cell phones size less than 4,7''.
The pack is constructed in water-repellent and tear-resistant high density nylon, so it is suitable for outdoor usage.
It can be used as a waist pack or a shoulder bag (Figure 50).

The mother board and the battery fit in the main pocket, while the other features can be easily attached. In addition, it has side pockets for a water bottle and a cell phone.
Price: 15,60 €

Figure 50. Wotow Military Single Shoulder Bag

Final backpack device

The team has decided to use the Pellor Black Utility Tool Pouch Detachable (Figure 51) for the final product as it is the closest device near the decided design (Figure 52). The choice does also take following characteristics into account:

- Suitable for outdoor activities.
- Multifunctional and practical.
- The pouches are detachable, that gives the user freedom to choose how many pockets he actually needs apart from the main one.
- It has an adjustable belt.
- Waterproof, as the material is high density Oxford.
- It can be used as a waist belt or a shoulder bag.

Figure 51. The Pellor Black Utility Tool Pouch Detachable

Figure 52. Decided design

7.1.2 Application

The interface of the product is an important part of the product that can be improved by using new technologies. A lot changed to the interface, mainly:

- The look and design is in the same line as Doble's house-style.
- Features like a map and the possibility to make a route has been added to the interface.
- The user has to interact with the product.
- New technologies like augmented reality make it possible to create user experiences.
- Results of measurements has been simplified for unskilled users if required.
- Using touch screens makes the product more intuitive in today's standards.
- Both 2D and 3D views are possible.

The interface has been prototyped in proto.io. A full view of all the screens has been put in the PDF of the interface. An unambiguous design with a clear colour, form and lay-out code has been created using today's interfaces as inspiration (Figure 53).

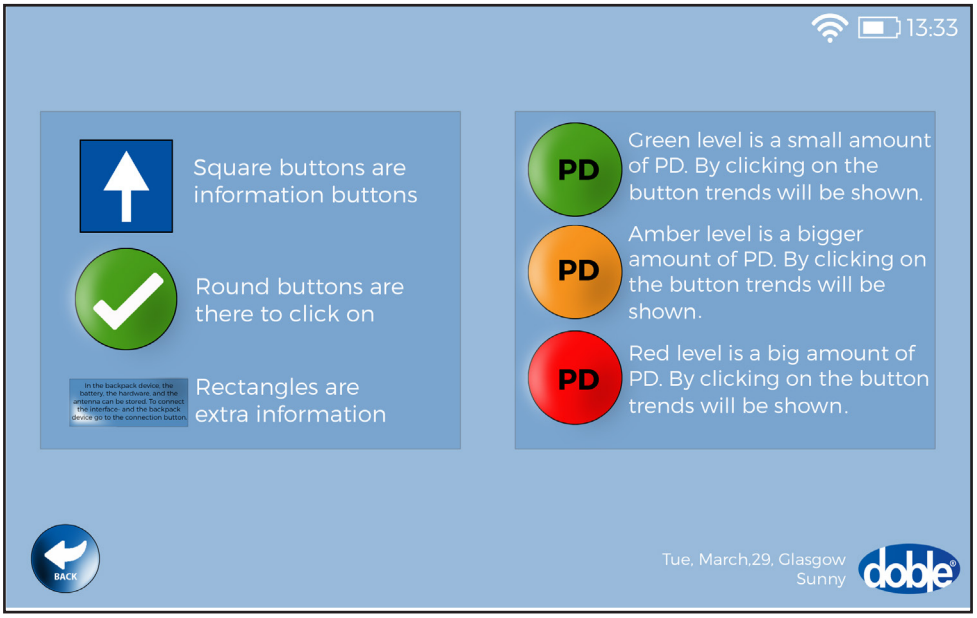

Figure 53. Button code

Mainly the interface consists six main options, with all their extensions (Figure 54). The map, scan and connection options are by far the most important ones.

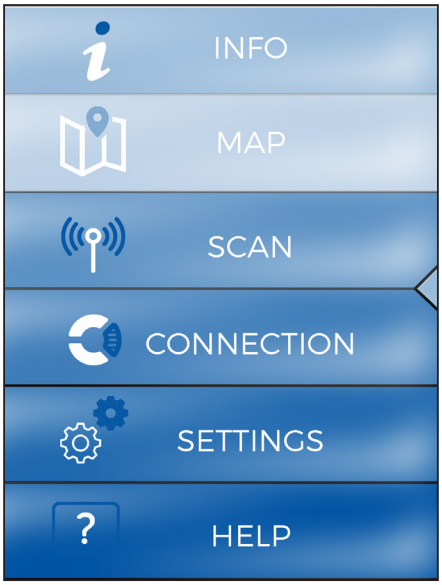

Figure 54. Main menu

If the user chooses the map option, he has to choose between a existing map, if they are previous measurements in the cloud available, or to create a new map. An existing map would be a map with saved paths/ routes from previous users and previous measurements. Critical points where partial discharge has been measured are shown on the 2D map by the colour code (Figure 55) . Next to that the user has the option to follows a described path or to create his own path through the substation.

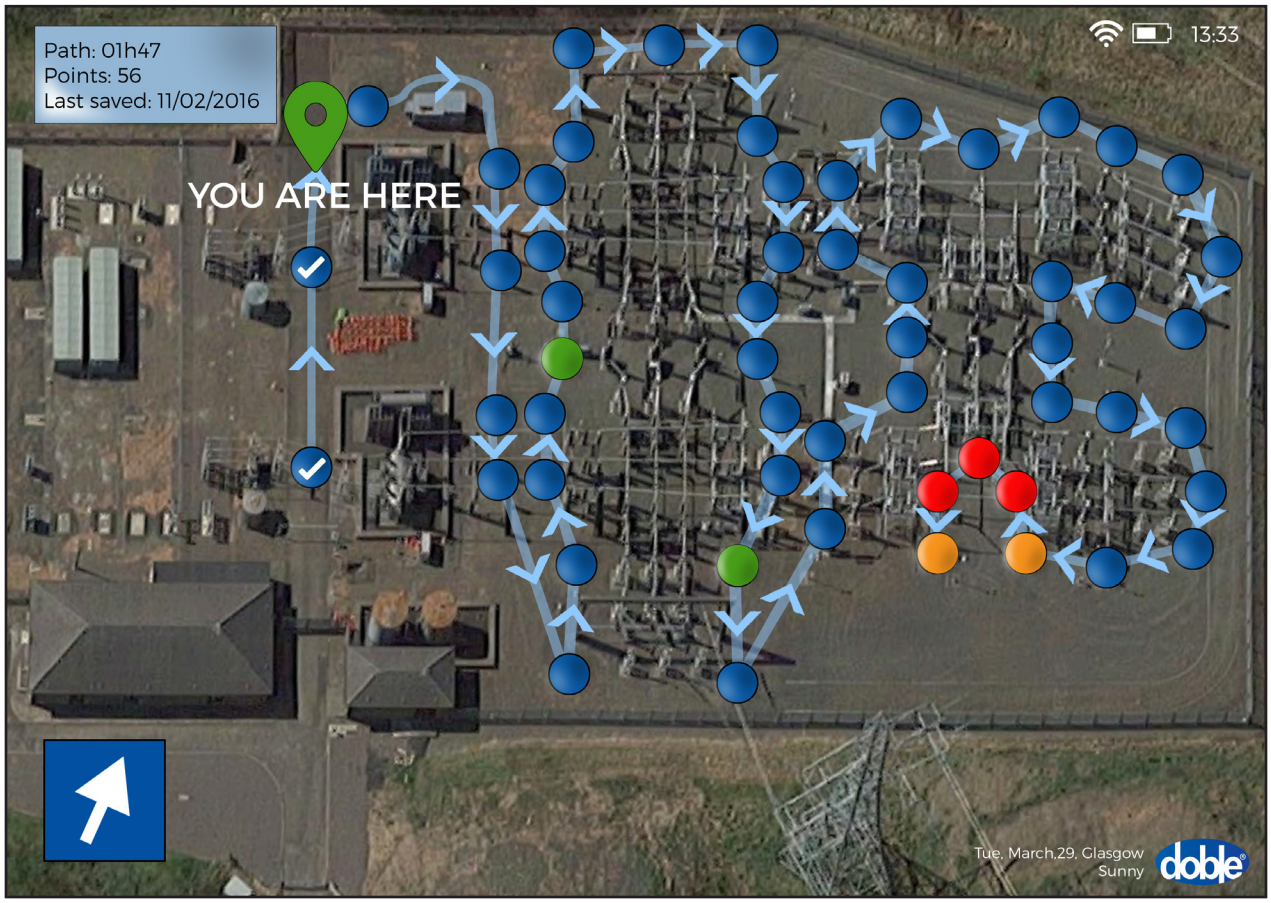

Figure 55. Map with path

Another main option in the menu is the connection. In section 7.1.7 the connection is explained in detail. Under this option the user can choose to connect to the cloud, to download folders from previous testing or connect the interface to the backpack device and the antenna. In this way the user can start scanning RFI in the substation.

Scanning the RFI in the substations can be done on a 2D level or optional on a 3D level. Notice that for the 3D level, the customer needs to buy the camera option. If the user only use the 2D level, the simplify version of the result is shown on the map by the colour code. The check symbol in the coloured bubbles (Figure 55) are there to show if the new scan has been done. In Figure 55 the bubbles with the check symbol are blue, this means that there is no partial discharge on these spots. If the point would turn green, amber or red, partial discharge would be present on different danger levels depending on the colour. The simplify colour code version is possible by using the PAPR (Peak to Average Power Ratio) of the measurement. This is an average number of the difference given to the spectrum of RFI. In the 3D version, the environment is shown on the interface. When the scan is done, a coloured bubble will show the colour code (Figure 56) on the measured spot. If more information about the partial discharge is required, it is possible to click on the coloured bubbles, this will lead to detailed graphs of the spectrum or comparisons between different measurements done on different moments.

Figure 56. Result of scan in 3D vieuw

The detailed views of the measurement can be divided into two graphs. Firstly the user can see the graph showing the spectrum of the RFI that the PDS100 is using already. If the user does not want to have that much details he can have simplified version of that table using the colourcode to show where in the spectrum the problem is. This graph (Figure 57) compares the measurement with the backround taken outside the substadion. The PAPR showed at the moment of the scan (Figure 56) is the simplified version of this both scans and can be seen as the average of that spectrum.

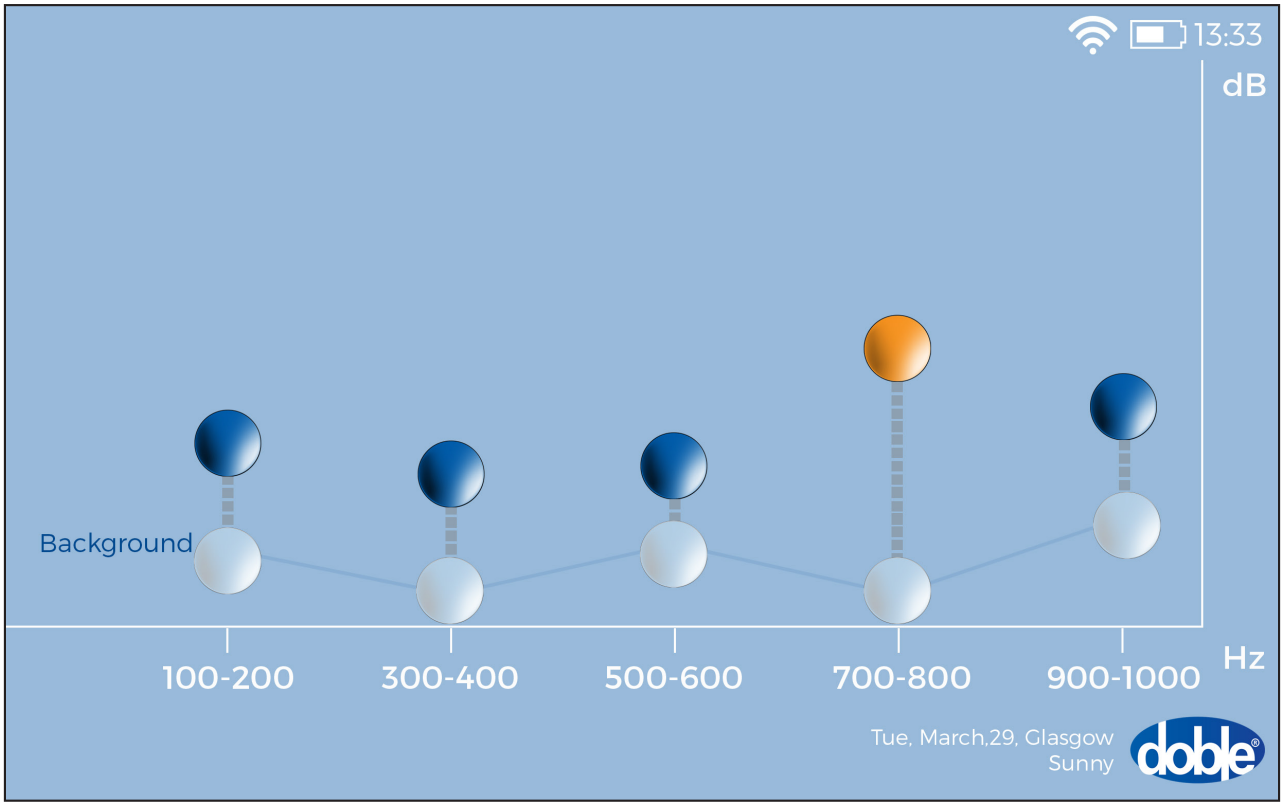

Figure 57. Simplified version with the colour code of the spectrum graph

A new feature of the new interface is the ability to compare different measurements with each other. This can also be done with the PAPR numbers of the different measurements in time from the same spot (Figure 58).

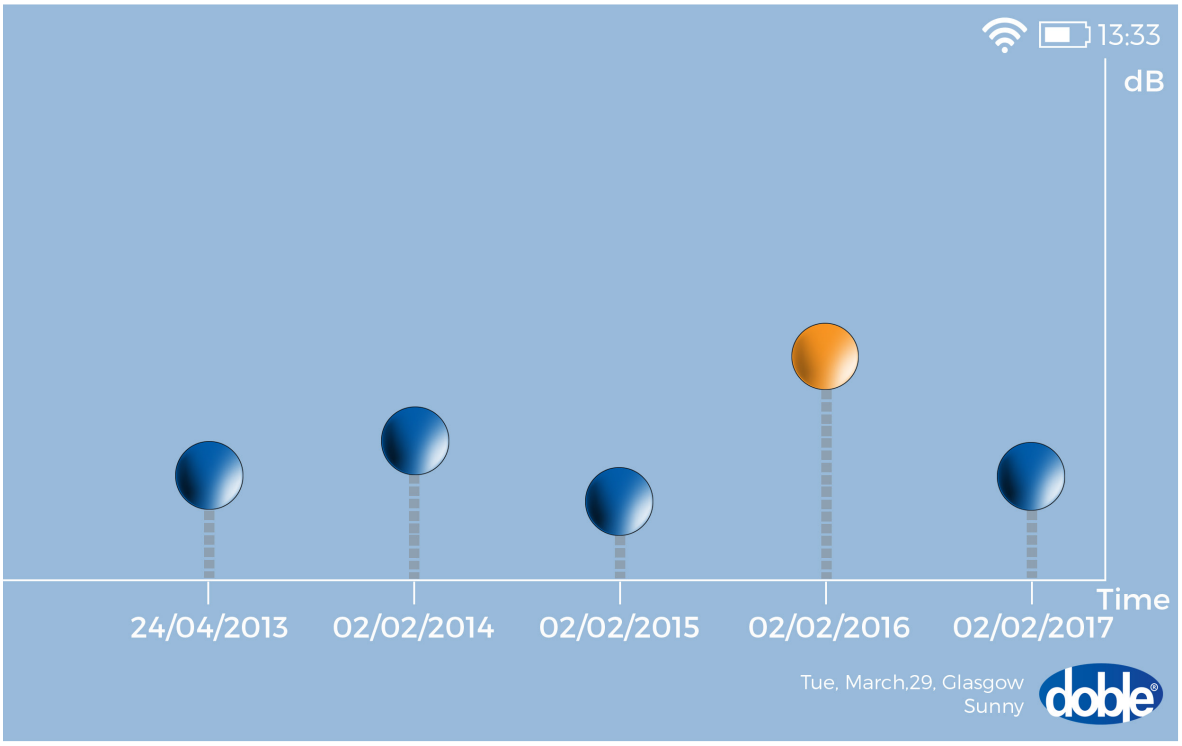

Figure 58. Comparing the PAPR from different measurement in time from the same spot

If more information is required, the comparing of the RFI spectrum in time are possible (Figure 59). The user can choose how many dates he requires to compare. The colours on the background show if the problem is big or not. If the last measurent is in the red zone, something should be undertaken in the substation, otherwise the measured element could explode.

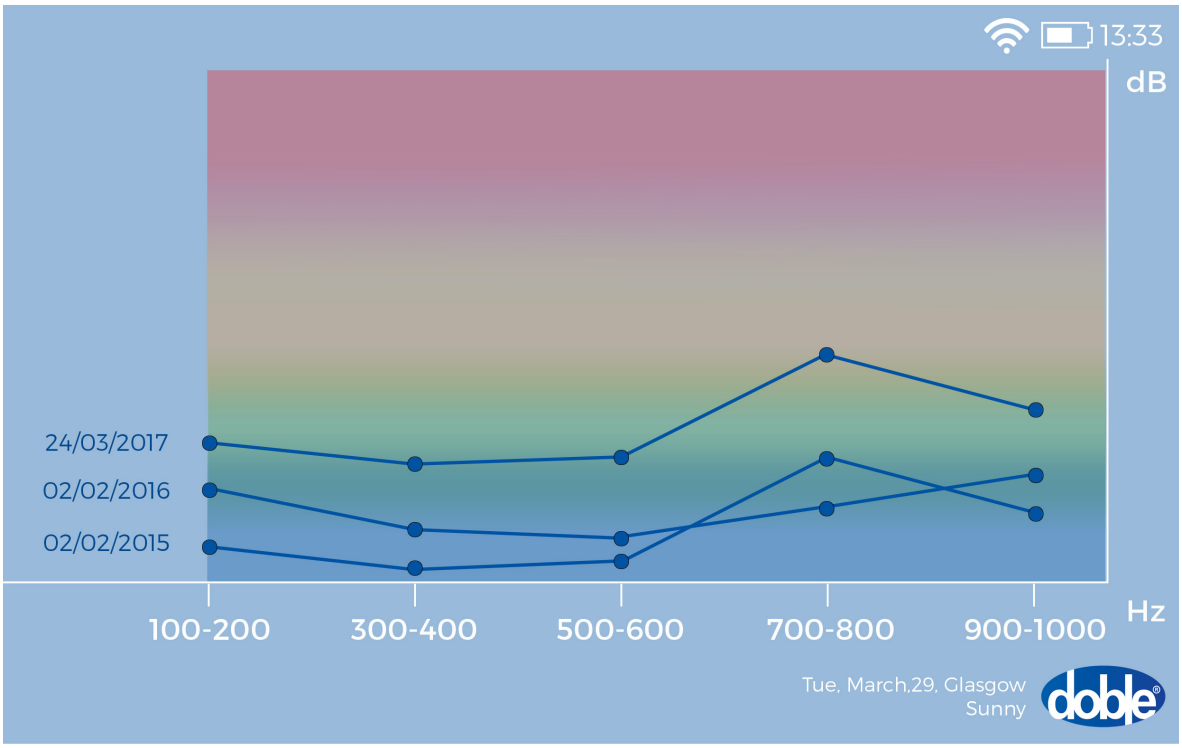

Figure 59. Comparing the PAPR from different measurement in time from the same spot

7.1.3 Tablet /Smart-phone

The selection of the tablet or smart-phone is a very important stage for the product. It is needed to distinguish two different kinds of customers: the ones that need the ATEX certificate for entering the area and the ones that do not need it. Therefore the recommendation is to have two different tablets and leave the choice to the client to choose which one is more adequate for the situation.

Getac 710-Ex

In case the customer needs a tablet with the ATEX certificate for Zone 2, the best solution is the Getac 710-Ex 5 (Figure 60). This tablet is perfect for data collection, it is compact and powerful, with a weight of 800 gr and a battery duration up to 10 hours. The operative system is Android OS and it has a 7" display that the user can operate with heavy gloves.

Figure 60. Getac 710-Ex tablet

This tablet is very resistant. It can stand a drop from 1,82 m and is able to work in critical environments with an operation temperature from -20 ˚C to 50˚C. Next to that it includes LumiBond technology, which makes it readable with sunlight. It also includes a fast and accurate option of GPS for outdoor clients. This tablet also combines Lattice SiRFstarIV GPS chipset, E-compass and 3 axis accelerometer, for a faster location and an improved accuracy of 2,5 m. The technical specification can be consulted in appendix K .

Mitac Ulmo

Mitac Ulmo is a rugged Tablet Android platform produced to satisfy a new range of business requirements. With its industrial and mechanical design the tablet achieve a high performance combined with being compact and ergonomic. It is also waterproof and is drop resistant with a tolerance of 1 meter. its operating temperatures are from -10˚C to 50 ˚C (Figure 61).

Figure 61. MiTac Ulmo tablet..

The Ulmo has a 7" capacitive touch display that can be used with gloves. The unit has an integrated, high capacity battery that can last up to 8 hours of use and it also includes GPS + AGPS. For checking the full technical specifications of this product go to appendix K .

7.1.4. Camera

The camera recommended to use for the product is PANNOVO mini portable camera, available to buy on amazon (Figure 62) . It has a good video resolution of1080P and it is small and compact, with a weight of 16 gr. This camera has the possibility of Wi-Fi connection long or short range.

Figure 62. PANNOVO Wi-Fi mini spy camera.

The camera has the following specifications:
- Video Format AVI
- Video Resolution 640x480 15 fps
- Cycle Record
- Supports Max. Capacity 32 GB
- Battery Actual Capacity 200 mAh

7.1.5. Battery

The recommended external battery is the Lumsing Harmonica Series Dual-USB Portable Battery Charger 10400 mAh External Power Bank (black) (Figure 63). This one is chosen because it is a powerful compact and stylish device, with a high capacity Li-ion battery. It also has an affordable price of 11,82 €.

Figure 63. Lumsing Harmonica external battery.

Specifications of this battery are the following:
Brand: Lumsing
Capacity: 10,400mAh
Input: 5V 1.5A
Output: 5V 1A/ 5V 2.1A
Size: 13,8 x 5,9 x 2,1 cm
Weight: 340 gr
Warranty: 12 months
Time to fully charge: 6,5 hours

7.1.6. Material selection

Phone/tablet holder
A detailed comparison and review of materials with these properties can be seen in section G of the appendix. The shortlisted materials that have the most suitable properties are shown below:
- Polycarbonate
- ABS (Acrylonitrile Butadiene Styrene)
- CFRP (Carbon Fibre Reinforced Plastic)

The finalised list of suitable materials for the tablet holder is shown below (Table 8), along with their mechanical properties.

Material	Price (€/kg)	Density (kg/m^3)	Young's modulus (GPa)	Fracture toughness (Mpa.m^0.5)	Hardness (HV)	Electrical Conductivity
Polycar-bonate	3.39	1175	2.22	3.35	19.7	Good insulator
ABS	3.23	1110	2	5.48	10.45	Good insulator
CFRP	2.28	1550	109.5	13.06	16.15	Poor conductor

Table 8. Mechanical properties of finalised materials (CES EduPack)

Note: All values are an average of a given range from CES EduPack

Sustainability and the Environment

Since there is a large awareness of the impact that a product and the process of manufacturing the product has on the environment, the sustainability of each material must be analysed to locate options that are environmentally friendly and can be recycled/ reused with a low Carbon dioxide footprint.

		Polycarbonate	ABS	CFRP
Primary Production	Embodied Energy (MJ/kg)	79.7	95.1	476.5
	CO2 footprint (kg/kg)	3.115	3.835	34.65
Material processing	Polymer moulding CO2 (kg/kg)	1.61	1.55	Not Applicable
	Moulding CO2 (kg/kg)	Not Applicable	Not Applicable	1.755
Material recycling	Recyclable	V	V	X
	Embodied Energy (MJ/kg)	49.55	46.3	Not Applicable
	CO2 footprint, Recycling (kg/kg)	8.6	3.6	Not Applicable
	Recycle fraction in current supply	5.55%	0.75%	0.75%
	Biodegrade	X	X	X
	Toxicity rating	Non-toxic	Non-toxic	Non-toxic
	Renewable	X	X	X

Table 9. Comparison of environmental performance of materials (CES EduPack)

Note: All values are an average of a given range from CES EduPack

From a sustainability perspective, CFRP is not suitable since it is not recyclable and also consumes a substantial amount of energy and CO2 during primary production. The performance gains would not be worth the environmental costs, especially considering that ABS and Polycarbonate have suitable mechanical properties for the application and have much a lower CO2 footprint overall, and can be recycled, with ABS having a lower overall CO2 footprint than PC.

Final Selection
The most suitable material for the product from a mechanical and environmental perspective, is ABS, since it will offer a good finish to the product and is also UV resistant as well as being able to cope with the large temperature fluctuations that the product will experience in different weather conditions. The selection process is in appendix ??

Backpack/Vest
The selection process can be viewed in section G of the appendix.
The material to be used for the backpack is Cordura, a rip stop nylon with strong wear resistance, combined with a polyurethane coating that gives it waterproof properties. The straps for the tablet holder would use normal Cordura, with Velcro patches stitched onto to allow adjustability.
However, this would be the ideal fabric but since commercially available options will be used, it may not be possible to find a solution that already uses this fabric, but still use one that is able to meet the design requirements.

7.1.7 Manufacturing

Manufacturing overview and location
Now with the material selected, a review of the manufacturing process can be done. The manufacturing process to be used is injection moulding which is a popular process throughout the world. since the selected material, ABS, is a thermoplastic and has suitable properties for this process. A description of the injection moulding process can be found in section L of the appendix. The injection moulds are a key part of the process since they define the fit and finish of the final product. Therefore, the correct moulds need to be selected, with the selection process being viewed in appendix L. From this process, it can be seen that a type 104 mould would need to be used to meet quality and manufacturing tolerances for the specified quantity.

The location of manufacturing is essential to the quality of the product and in terms of cost and logistics. Research of the location of manufacturing was done and can be viewed in appendix L, with the conclusion being that manufacturing should be kept within Europe or the USA to maintain quality, especially for a low volume high quality product even though there may be more cost effective methods elsewhere in the world.

Fabric parts
Since the vest and the straps will be commercially available options, the parts would be ordered directly from the supplier and this means that it can be stockpiled to be used in the assembly process.

Electrical components
The variety of electrical components used in the final product would be purchased in bulk from the suppliers and would be stockpiled to allow the required number of units per annum to be produced on demand. The only exception to this would be the tablet, since this would be bulk ordered from the supplier but would be delivered using a just in time supply system to be used for confirmed sales.

Final assembly
The final assembly of the components would be done by an assembly supplier that would be one of Doble's partners. This would ensure that quality is kept to a high standard. The key steps of the final assembly would be:

• Insertion of the electrical components into the vest.
• Wiring the electrical components together.
• Assembly of the tablet holder components using 4 standard M3 screws, with certain parts of the holder bonded together using a strong glue.
• Packaging and testing of the product before being distributed.

This would be the logical assembly sequence for the assembly process. Due to the design of the product, the assembly process will be labour intensive apart from the tablet holder, which could utilise automated assembly if preferred.

7.1.8 Connection

For the final connection between the two devices, the team chose to use the Wi-Fi type n. This provides the product with an adequate data transfer rate and a permanent connectivity method. Once the system decided, it is needed to choose how it will be implemented. After a comparison of the existing wireless adapters in the market, the chosen one is the tp-link TL-WN725N USB (Figure 64). Mean reasons are listed below:

• Miniature design and lightness to be as convenient as possible.
• Speedy wireless transmission, up to 150 Mbps.
• Internal antenna.
• Easy setup utility.
• Advanced security: Supports 64/128 WEP, WPA, PA2/WPA-PSK/WPA2-PSK(TKIP/AES).
• Good price/quality rate.

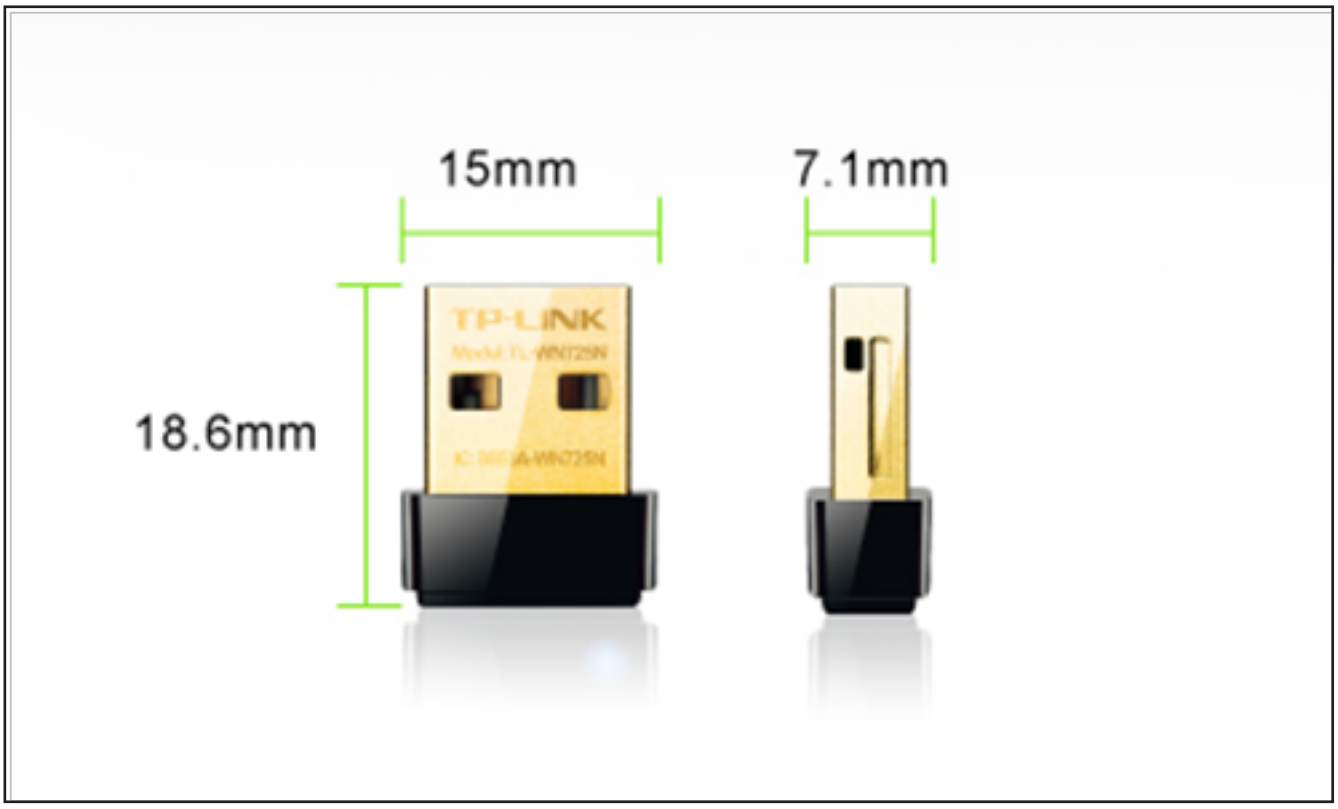

Figure 64. Tp-link TL-WN725 USB image with its dimensions.

The specifications of this product can be read in appendix H .

7.1.9 Location

The tablet that is used is equipped with a GPS chip. This chip will determine locations while using the product. If the customer buys the basic device (with the cheaper tablet option), the GPS chip provided can guarantee an accuracy of 5-8 metres. This option is not enough if the client needs a high accurate location of the measurements but it can be enough if it is not needed. If the customer decides to include the superior tablet, the supplier guarantees an accuracy of 2,5 metres, which represents an important improvement that makes the device suitable for more precise surveillance.

If the accuracy achieved with the second tablet is not enough for the customer needs, the possibility of including the Trimble R1 GNSS Receiver is also available. This differential global positioning system guarantees a sub-meter precision thanks to the corrections obtained using Trimble's reference sites. The DGPS receiver meets all the resistant, physical and connectivity requirements, being the ideal solution for clients that require a high accuracy.

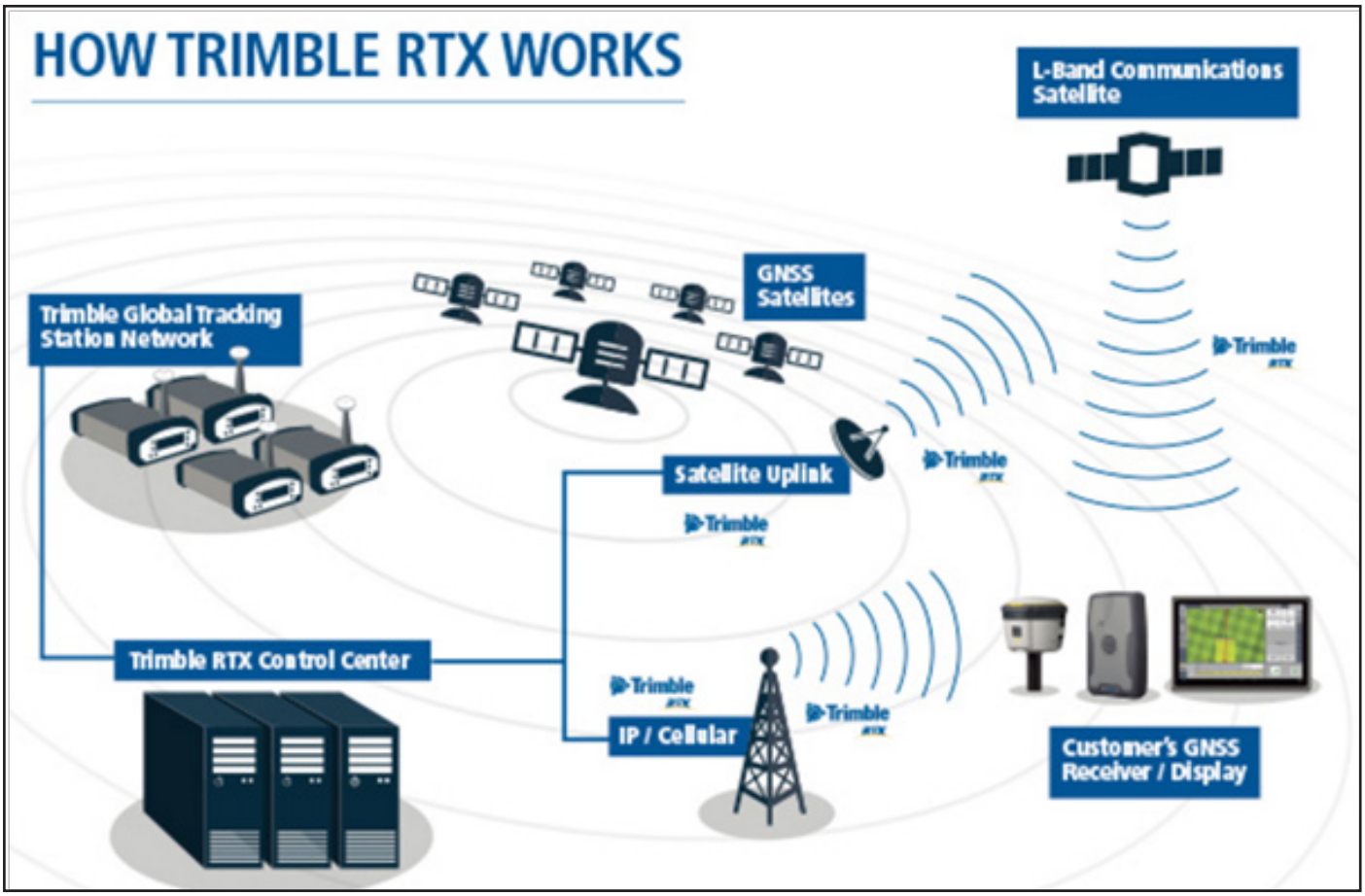

Figure 65. Operating overview on Trimble R1 GNSS Receiver

The different alternatives available on the GPS/DGPS technology provide a robust and effective solution for outdoors locations no matter which level of accuracy the customer needs. However, these systems are not suitable for indoors and underground surveillances. In these situations, technologies with a price that make them suitable for this project nowadays are not available. However, the indoor location and positioning field is being widely studied and investigated and in the nearly years new and cheaper products are going to appear. Existent pseudolite based technologies like Locata are a solution actually in use in these kind of environments, and they are also the base for the new and cheaper products actually in development.

7.1.10 Conclusion of the final product

Table 10 includes all the chosen features and systems for the final product. The product will be divided into a backpack device with all the smaller systems and the camera, a forearm device with the tablet and the handheld antenna (Figure 66).

Tablet holder	Backpack device	Tablet	Camera	Battery	Connection	Location
· custom made tablet holder in ABS Other possible options: · 4smarts Marathon Universal Sports Armband · Sacci Hook shoulder harness		· Mitac Ulmo Other possible option: · Getac 710-Ex	· PANNOVO mini portable camera	· Lumsing Harmonica	· Wi-Fi type n. · tp-link TL-WN725N USB	· Tablet with a GPS chip Other possible option: · Trimble R1 GNSS Receiver

Table 10. Chosen features and systems for the final product

Figure 66. Visualization of the final product

Future features

The new product can provide the user with a 2D map of the substation with highlighted spots indicating where the measurements were taken. This feature is a great improvement over the previous PDS100, but it could be even enhanced in the future using new technologies current in development stage, being able to create 3D maps of substations. As the new design includes a camera, it could be an interesting idea in the future to create a 3D map of the substations using the images taken by the instrument, providing companies with real models of their installations that could be used in many different ways. For example, with a high accurate model, surveillance could be planned from the office before going to the substations, or a study of the substation could be done if the company want to do any improvement there. It would be also possible to take physical measurements like distances or heights without having to go there.

Nowadays some products already provide this feature, and one example is the app Canvas, available for iOS devices. Attaching a special sensor into the device, a 3d model can be obtained after a quick scan at the surroundings. Once the 3d model is done, there is the possibility of creating a CAD file of the scanned space.

Figure 67. Canvas attached sensor

However, it would be interesting to incorporate this feature to the tablet used in the product without having to add more attachments. Here, the future is “Project Tango” from Google. This technology was announced by Google in 2014, and after some years of development it finally become reality in a smart-phone device presented by Google in 2016. In 2017 the first commercial smart-phones incorporating this technology were launched by ASUS, a path that surely will be followed by many other brands in the following years.

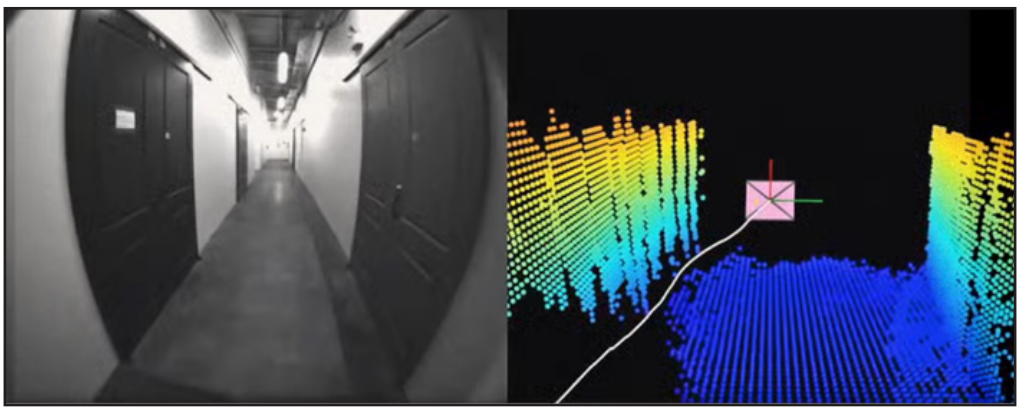

Figure 68. Project tango. In the left the image seen by the camera and in the right the project tango representation.

7.2 Expected benefits

The benefits of the product the team propose would be the following ones:

· The product is modular on different ways: The purchaser or user has different options (Tablet, 2D or 3D application, backpack device,...)
· The tablet holder is lightweight and portable.
· The tablet holder will offer increased ergonomics and integration for the user, while being sustainable by being manufactured with recycled plastics and itself being able to be recycled.
· The tablet holder is also able to provide a wide range of adjustment in terms of the device used.
· The tablet holder is suited for both left and right handed people.
· The utility belt is adjustable and follows the safety regulations.
· The utility belt divide the weight of the product all over the body of the user.
· The user is able to choose which utility belt suits him best.
· The user will be able to interact on an exciting way with the product because of it's intuitive and new interface.
· The user can be either an expert or an unskilled user, as different methods of displaying the data have been developed.
· A comparison mode is added to the interface; in which you can compare the actual data with past measurements in a form of a trending graph.
· Easy display of the data, with the possibility of further analysis.
· Virtual reality mode which uses artificial vision for its implementation.
· The location system will allow the user to know their exact location inside the outdoors substations.
· A map can be created to display the data in a orderly manner.
· The user can save the results of the measurements easily to a cloud.

7.3 Expected risks

The product proposed has some risks that should be taken into account.

· In case of extreme low temperatures, below 0 ˚C, the wireless adapter can start to experience some problems.
· Interference in the connection due to high voltage environment.
· In humid or rainy days, the camera can have a poor visualization of the environment.
· The components inside the vest are at risk of damage if not used in the correct manner.
· If not used with a waterproof case, a non-waterproof phone/tablet may not be able to function properly in poor weather conditions.
· The processor, Red Pitaya, operating temperature is from 5 ˚C until 30 ˚C, so in extreme temperatures it can start to malfunction.
· The cost of the improved location system is uncertain.

8. MARKET ANALYSIS

8.1 Segmentation

The markets that the product will be aimed at can be split into two distinctive groups that can be segmented further:
• The purchaser (Table 11)
Who is going to buy it and why are they buying it?
• The user (Table 12)
Who is going to use it and why are they using it?

8.1.2 The purchaser

Market segment	Description
Electrical generation companies	Companies that are responsible for the generation of electricity in different ways such as hydroelectric, tidal, coal, nuclear, solar or any other method of electricity generation that requires insulated transmission lines and/or transformers. These companies would be buying the product in order to use it for preventative maintenance of their assets. Electrical distribution companies is a national, multinational and also a global market and therefore is a sizeable market, with net electricity generation in 2012 totalling 21.6 trillion kWh (U.S Energy Information Administration, 2016). Examples of electrical generation companies are: • British Gas • Centrica • EON • EDF energy
Electrical distribution companies	The electrical distribution infrastructure and ensure that electricity is supplied to homes and businesses globally. This will be a large market since this is a crucial infrastructure that requires continuous preventative maintenance to ensure that there are no power shortages due to failures in substations or transmission lines from partial discharge. As an indication of the market size, there are 2400 electrical distribution companies just within Europe that could be potential customers (Eurelectric.org, 2017).
Pharmaceutical industry	Pharmaceutical companies are large users of electricity and will usually have a substantial power distribution systems inside some of their larger manufacturing/processing plants around the world that will require proactive maintenance in order to keep those plants running and keep up with demand. As an indication of market size, examples of pharmaceutical companies and the number of plants they control are shown: • GSK- Manufacturing and R&D sites around the world in 36 countries (Gsk.com, 2017) • Pfizer- 79 manufacturing plants around the world (Bush, 2010) • Novartis- 24 major plants for manufacturing and R&D globally (novartis.com, 2016)

Market segment	Description
Petrochemical industry	The petrochemical industry is one of the largest industries globally and has a global infrastructure of extraction, processing and distilling plants, all of which require considerable amounts of electricity to run the required processes, and will mean some plants will have their own substations and transmission systems that will require maintenance and could be a potential market. Examples of major petrochemical companies and the size of their operations gives an insight into market size. • ExxonMobil- Operations on 6 continents (ExxonMobil, 2017) • Petronas- 3 refineries, 18 petrochemical plants and 11 blending plants globally (Petronas.com.my, 2016) • Total- 23 refineries and petrochemical plants globally (Total.com, 2017)
Mining industry	The mining industry is power intensive, with power needing to be supplied to often remote mines to power ancillaries and any on site processing required for the extraction of ores or minerals. This means that some mines will have their own transmission lines and substations to supply power. The size of this market is substantial, with over 17 million metric tonnes of worldwide mining in 2014 (Reich, Schatz & Zsak, 2016).
Manufacturing industry	The manufacturing industry is a large and expansive industry, and could be associated with anything from food processing to car manufacturing. These production lines and associated machinery will consume large amounts of electricity, and larger manufacturing plants may have their own substations. This market can be segmented further, with markets being considered in: • Automotive • Aeronautics • Electronics • Ship building • Food processing • Chemicals • Textiles

Table 11. The purchaser

8.1.2 The user

Market segment	Description
Unskilled technicians	Basic technicians who will have come from a technical background and are tasked with using the product to do tasks such as routine checks and maintenance of substations. This is the most common user of the product and exists globally, operating in a variety of different types of substations.
Skilled/expert technicians	Technicians that have a technical background, usually electrical, and are experts at using the product and in understanding and detecting partial discharge. Skilled technicians are usually older than unskilled technicians and have more experience than them. They are usually tasked with dealing with any problems that have been detected by the unskilled technicians in substations.

Table 12. The user

8.2 Competitors

Market analysis and Risk assessment of competitors

The USP (Unique Selling Proposition) of each competitor will be analysed in order to identify gaps in the market that the final product can fulfil with its own UPS.

Competitor	Competitive Risk	Description of Competition and Assessment of Risk
HVPD PDS Insight	High	The Insight consists of a handheld unit that completes PD measurements. This is then viewed via a small colour screen. Further analysis can be done on an android tablet app via Bluetooth. The key USP is of the Insight is that it is highly adaptable due to various measurement methods and its use of current technology. The final product mitigates this by focussing on being highly portable with all components mounted on the user's body while retaining the same touchscreen user interface as the Insight. The final product has less features than the Insight but are more functionality focused. It can also be able to accommodate either a smartphone or a tablet, not just a tablet like the Insight.
EA Technology Ultra TEV	High	The UltraTEV uses a range of attachments to enable it to do PD measurements, which are then displayed on a large touchscreen unit that is handheld. The main USP of the UltraTEV is the use of TEV (Transient Earth Voltage) and its adaptable measuring solutions. The final product reduces this USP by having a sleeker, more modern design, since the UltraTEV has a bulky cumbersome design. The final product's acoustic measuring system is also more minimalist and does not require as many attachments.
Megger UHF PD	Medium	The Megger UFH PD has a similar system to the EA UltraTEV, in that it uses a range of attachments to measure PD and display it via a large touchscreen. Its main USP is that it combines two different PD measurements (HFCT and TEV) to carry out measurements and analysis within one unit. Despite only using one sensor, the final product has more adaptability than the Megger in that results can be easily stored in the cloud and viewed on any device capable of having the app, whereas the Megger has to use hardware to transfer data.

Competitor	Competitive Risk	Description of Competition and Assessment of Risk
Qualitrol PDM/ GIS monitor	High	The Qualitrol has all components stored inside one large carry case, with a large touchscreen interface. This allows it to have large computing power. The main USP of the Qualitrol PDM/GIS is its software, which is capable of automatically detecting faults and logging them. The software used for the final product can detect faults, but it cannot automatically log them. But the Qualitrol's disadvantage is its poor portability.
BAUR PD-SGS	Low	The Baur PD-SGS is a handheld device that measures using both TEV and acoustic sensors. Its key USP is being able to instantly detect PD and the severity of it via a 'traffic light' system. The PD-SGS is a low risk because it offers no detailed data if required and cannot store previous data, only real time data. This means that although it can clearly indicate the presence of PD, it offers no analysis data. The final product's software combines both this instant PD detection as well as the analytical tools.
Techimp Aquila	Medium	The Aquila is a similar design to the Qualitrol, but uses an embedded industrial tablet to view data. It is designed to be used with different accessories that allow different types of assets to be measured. Its key USP is ruggedness, since all the components are stored in a large carry case that is waterproof. The final product is more exposed and more susceptible to damage than the Aquila due to its focus on ergonomics and the overall user experience but has the same capabilities as the Aquila but in a much smaller package.
Ndb XDP-2	Low	The XDP-2 is a portable handheld device with display and uses a range of accessories. The main USP of the XDP-2 is an in-built speaker that gives an audible output of the PD measurement. The risk of this is low since its USP is not practical in certain applications where ear protection must be worn, such as in a substation. It is also not waterproof, only splash proof, meaning it cannot be used in poor weather conditions.

Competitor	Competitive Risk	Description of Competition and Assessment of Risk
Sonotec Sonaphone	High	The Sonaphone is a handheld touchscreen device using proprietary data analysis software. The main USP of the Sonaphone is the screen. Which is a large 5 inch TFT touchscreen display that offers a modern, up to date user interface. The final product mitigates this by offering adaptability in terms of touchscreen size, with either a smartphone or a tablet being able to be used. The final product also uses the cloud for data transfer whereas the Sonaphone uses hardware for this.
Sonotec Sonaphone pocket	Low	The Sonaphone pocket is a more basic version of the Sonaphone, using hard buttons instead of a touchscreen display, and a basic monochrome display. Its main USP is that it is highly portable due to its compact dimensions. The final product mitigates this by being more integrated and offering more advanced data and analytical features, since the Sonaphone pocket can only display real-time data and does not automatically detect PD, it only gives a numerical value.
PMDT PDetector	Low	The PMDT is a handheld device that detects PD using acoustic ultrasonic sensors. Its key USP is that RFID (Radio Frequency Identification) tags are used with the product for asset location. The final product mitigates this by using a camera as well as an advanced location management system to locate assets.

Table 13. Market analysis and Risk assessment of competitors

Conclusions of analysis

There are a large variety of competitors out there that use different methods to solve the same problem and achieve this with very strong USP's, some of which the final product cannot match. However, the final product is superior to certain competitors such as Ndb and the Sonotec Sonaphone.

8.3 Marketing plan

In order to successfully take the designed product to the market, an accurate and exhaustive marketing plan is needed. This marketing plan must go through all the important aspects involved in the launch of the product. A business canvas map (Table 14.) has been created to have an overview of main aspects and for having a clear view what the product is about and why it could be important for the potential buyers. The developed product is a specialized device that is going to be acquired by companies with very special needs, essentially companies that deal with great amounts of high voltage electricity.

Doble is an established brand in the partial discharge detection market and it has an existing customer base which makes them leaders in the sector. For this reason, customers trust the company and the potential customers know there is a guarantee that the product is successful and reliable and succeed in doing its job.

The customers are going to use the device in order to do a proactive maintenance, assessing their installations trying to avoid possible problems that can lead into big economic losses or even the death of employees.

The device is sold in different versions. The basic one includes the simpler tablet with the less precise location and it is aimed to customers whose only need is to assess their installations without caring on the exact locations of the measurements. The version with the more advanced tablet provides a better accuracy in the location, and the tablet comes with a certificate that makes it suitable for explosive environments. Finally, for those clients that need a sub-meter accuracy, a version with the Trimble R1 GNSS receiver is available, which provides DGPS location system. Having these three version gives the customer the option off acquiring the product that best fits their needs.

When acquiring this product, customers not only are buying the device but also the knowledge behind it. Companies will use this knowledge to save big amounts of money thanks to the proactive maintenance, for this reason they are willing to pay a considerable price for it. According to Doble premises the price for the basic device would be 6000 euros, which is considerably cheaper than the previous PDS100, that was sold at approximately 9200 euros according to Doble information. Therefore, as the previous device was really successful in the market, the potential clients, who want to renew their equipment, will find the new device with a cheaper price, very attractive. For the better versions of the product the price would be augmented accordingly with the improvement in the features provided.

For Doble, it is important to keep their image of trust and stay market leader in the sector. For this reason, key customers will have a 30% of discount in the final price of the product, as they are acquiring a bigger number of devices. By doing so, the relationship between both companies will be strengthened and this can also lead into sales of a wider variety of Doble products.

By selling this device, Doble starts a relationship with the buyer. Customers can use the product to assess the condition of their installations, but sometimes and specially with new clients, they may not have the required level of expertise to define which or where the problem is. Therefore, Doble offers their knowledge in the field in order to analyse customer problems and help them to define the problem and find a solution. This means that Doble not only makes profit by selling the product, but even a bigger amount of money can be earned with post selling services to the customer. These services help to strengthen the relationship between companies, as customers realize that Doble is there to help them solve their problems.

In order to improve the satisfaction of key customers, Doble could offer them a free service during a period of a couple of years consisting in providing a substitution device to them, in case their product has any malfunction, while it is repaired. This service could be expanded to no key customers if they do an annual extra paying.

As commented in the market segmentation, potential clients for this product are electrical generation companies, electrical distribution companies and companies with big needs of electricity such as pharmaceutical and petrochemical. As our potential clients are specialized companies, there is no need in using traditional advertising channels. Doble has the advantage that it is an established brand in the field and it is a leader in partial discharge detection. They also have an existing customer base due to the PDS100 and all the other products launched to the market overt the years. For this reason, it is likely that most of the potential buyers will come to Doble when they have a need in partial discharge detection. However, it would be interesting that the sales department of the company communicate to those potential buyers that this new product has been launched as an evolution of the successful PDS100. By providing these companies with information about new products, Doble sells an image of a company leader in R&D, constantly working for satisfying their customer's needs.

Doble is a company big enough to sell their products directly to most of the potential worldwide customers. However, the promotion and selling process could also be done through representatives and service companies, who would be able to reach those markets were Doble does not have a big presence.

<table>
<tr><th>Key partners</th><th>Key activities</th><th>Value proposition</th><th>Customer relationship</th><th>Customer segment</th></tr>
<tr>
<td rowspan="2">Key partners
· Electric companies
· Google earth
· Assembly companies
· Service companies

Key suppliers
· Tablet supplier
· Camera supplier
· Backpack device supplier
· Location system supplier</td>
<td>· Control substations
· Give advice
· Give services
· Analyse results
· Create testing products
· Proactive maintenance</td>
<td rowspan="2">· Cost reduction
· Proactive maintenance
· Safe work environments
· User interaction
· Up to date product
· High technology
· Ergonomic product</td>
<td>· The customer, both the user and the purchaser are relying on the safety of the product. Therefore they need to trust the company and the product. Next to that the customer expect extra services.</td>
<td rowspan="2">· The user
-> Unskilled technician
-> Globally
People all over the world with a different knowledge level and a different way of using the product.

· The purchaser
-> Generation companies in power stations
-> Transmission and distribution operators
-> Big users of electricity like petrochemical industries, pharmaceutical, etcetera.</td>
</tr>
<tr>
<td>Key resources
· Knowledge
· Accurate & punctual testing products
· Employees
· Partners</td>
<td>Channels
· Reaching the customers by positive feedbacks and new personal advertising.
· Delivery of whole package to the customer: the product, the expertise and services and the proactive maintenance.
· Selling channels: directly and through repres</td>
</tr>
<tr><th colspan="3">Cost structure</th><th colspan="2">Revenue streams</th></tr>
<tr>
<td colspan="3">Most important costs
Initial costs
· Case tooling
· Prototyping & testing electronics
· Engineering time
Annual fix cost
· Marketing & sales</td>
<td colspan="2">· The customer is willing to pay € 9200 (PDS100).
· Now the basic version of the product will be sold at € 6000.</td>
</tr>
</table>

Table 14. Business canvas map

9. FINANCE

In order to study the viability of launching the product to the market, a finance analysis is needed. To do so, an analysis of all the costs involved in the design and construction of the product have to be taken into account, as well as all the benefits from the expected sales and services obtained with the final product.

Doble has provided some valuable information for this part of the project, as with their experience they can estimate the costs of producing a product like this one with accuracy.

The company has also determined the expected sales for a product like this one. According to the information provided, it will be assumed that 200 units will be sold each year during the following 10 years. However, only the three first years will be analysed because these are the requirements for this project.

9.1 Costs

This product will be produced by Doble, a multinational company that has been running for many years. For this reason, the costs of running the company as well as rentals, general bills or loan repayments are not going to be taken into account as these costs are not provided by the company.

The fix costs are those which are not dependant on the number of devices sold, and they can be divided into two. In one hand the initial costs, that are applied in the first year and include all the costs from the developing stage. In the other hand, there are the annual fix costs, which are those that will be repeated every year.

Finally, there are the variable costs, which are those that are dependent on the number of devices produced.

• Initial costs

NAME	COST (€)
CASE TOOLING	36000
PROTOTYPING AND TESTING ELECTRONICS	36000
ENGINEERING TIME	240000

As the project is about a high-tech product, these costs were provided directly by Doble engineers.

• Annual fix costs

NAME	COST (€)
MARKETING AND SALES	40138

According to Doble, it should be considered that the money spent in the marketing and sales process is about the 20% of the building cost of the product, which is the cost of producing the 200 devices a year.

· Variable costs (per unit)

NAME	COST (€)
ELECTRONIC COMPONENTS	480
CASE	60
BAG/HARNESS	22
TABLET	398
CAMERA	16,45
ASSEMBLY COST	36

The assembly and the electronic components costs have been provided by Doble. They have also suggested a cost for the case according to the proposed design and their experience in the sector. For the camera, tablet and bag, the research done can be consulted in previous parts of this report.

According to these analysis, the cost of producing each device and the annual expenses of producing 200 are:

TOTAL VARIABLE COST PER UNIT = 1003,45 €

TOTAL VARIABLE COST PER YEAR = 200690 €

According to Doble premises, the selling price proposed is for the product with the basic tablet and all the calculations of this part have been made with these components. As explained in previous parts, more options will be given to the customers, such as using a more advanced tablet or including the DGNNS R1 from Trimble to increase the location accuracy. However, as Doble has not provided selling prices for this versions of the product, they are omitted in the finance analysis.

9.2 Breakeven analysis

The breakeven point will be reached when the money earned in selling devices is equal to the money spend in the design and production of these devices. From that point, the company will start having benefits.

According to the data provided by Doble, they expect to sell this product at 6000 €. However, key customers will have a discount of 30% in the price of the product. As Doble suggested, we will assume that 30% of the devices sold will receive this discount.

SELLING PRICE (€)	NUMBER OF UNITS SOLD	INCOME (€)
6000	140	840000
4200	60	252000

TOTAL INCOME DUE TO SALES = 1092000 €

In order to calculate the breakeven point, the following formula will be used:

$$\text{Breakeven point} = \frac{\text{Fixed costs}}{\text{Contribution per unit}} = \frac{\text{Initial costs+annual fix costs}}{\text{Selling price-variable cost}}$$

$$\text{Breakeven point} = \frac{352138}{((6000-1003,45)*0,7+(4200-1003,45)*0,3)} = 79,02 = 79 \text{ u.}$$

As shown in the previous calculation, the breakeven point is situated at the 79 units sold. This means that during the first year the investment will be recovered and Doble will start making a profit by selling the new device.

In the previous calculation, it has not been taken into account the income that Doble gets by providing post-selling services to their clients, but including this the breakeven point would be reached even faster. However, for the analysis of the first three years this income will be included. According to the information provided, it is assumed that between one third and half of the devices are sold to new customers. These customers are likely to need help from Doble during the first years using the product because of their lack of experience. It will be assumed that 40% of the devices sold will need further assistance from Doble, resulting in two days of work each with a cost for the company of 1000€ per day.

NUMBER OF NEW USERS	INCOME FROM ASSISTANCE
80	80000

In order to elaborate the profit and loss statement for the first three years, it is assumed that all the premises included in previous calculations are constant during this period.

· Year 1

Sales	€	€
Money of sales	1092000	
Money from services	80000	
		1172000
Cost of sales		
Variable costs	-200690	
		-200690
Gross profit		**971310**
Expenses		
Initial expenses	-312000	
Marketing and sales	-40138	
		-352138
Net profit		**619172**

During the first year, the company already makes profit as expected after calculating the breakeven point. Even including the initial expenses, the final profit is more than 6 hundred thousand euros.

· Year 2

Sales	€	€
Money of sales	1092000	
Money from services	80000	
		1172000
Cost of sales		
Variable costs	-200690	
		-200690
Gross profit		**971310**
Expenses		
Marketing and sales	-40138	
		-40138
Net profit		**931172**

In the second year, the profits will become even bigger because there are not the initial costs that were payed during the first year. As a result, the profit at the end of the year in more than 9 hundred thousand euros.

·Year 3

Sales	€	€
Money of sales	1092000	
Money from services	80000	
		1172000
Cost of sales		
Variable costs	-200690	
		-200690
Gross profit		**971310**
Expenses		
Marketing and sales	-40138	
		-40138
Net profit		**931172**

The statement for the third year is exactly the same than during the second year, as it has been assumed that the costs and sales were constant.
Analysing the results obtained in the profit and loss statements it can be seen that the launching of this product would be successful for Doble. During the first year the initial investments are already recovered starting having benefits, which will be even bigger in the second and subsequent years.

10. QUALITY / SUCCESS CRITERIA

The success and quality criteria is used to indicate the success of the product as a whole, using financial, environmental, and user experience as some of the indicators of success. Each criterion is given a rank to define its importance compared to the other criteria. As well as defining the criteria for failure and success, the implications of failure in each criterion will be discussed.

Quality /success	Criteria Description of Conditions for Failure / Success	Importance ranking (1 = most important)
Number of sales	Success would mean meeting the target of 200 units per annum or more. Another indication of the success is growing demand for the product on an annual basis. Failure would mean not being able to meet the target of 200 units per annum or an overall decline in the sales of the product. This would lead to a loss of revenue for Doble and may mean that they make a loss from being unable to recover the manufacturing costs.	2
Rate of return	This is the income from the investment into the product and is displayed as a percentage. For success to occur, this should be as high as possible to retrieve all expenditure. This is critical since it defines whether Doble will make a profit or a loss from the product. If this value is low, it means that it may take a long time to make a profit from the product, or not at all if this value is too low. The implications of a low rate of return is potential cash flow problems due to investment costs, potentially obstructing future investment. If a loss occurs, this may reduce the net worth of Doble and again, may hinder future developments.	3
Sustainability	The product needs to use sustainable products that are either recyclable or biodegradable, or is itself manufactured from partly recycled material. This needs to be achieved without affecting the performance of the product. This would be measured in the CO2 used in the manufacturing process and also the percentage of recycled materials used in the product. Success would mean the product being able to use sustainable, environmentally friendly materials that are recyclable and would allow Doble to help meet regulations surrounding the environment. It could also increase sales, since this will be appealing to customers that are environmentally conscious. If this is not met, then there may be problems with getting the product to comply with environmental standards that are required. It may also soil the reputation of the company, with the potential of customers viewing the company's lack of environmental awareness as unethical.	4

Quality /success	Criteria Description of Conditions for Failure / Success	Importance ranking (1 = most important)
Manufacture return rate	This is a measure of the profit from each unit that includes the cost of manufacturing that unit. For success, this needs to be maximised (low manufacturing cost, high selling price) to maximise the profit gained from each unit. If this is low (high manufacturing cost, low selling price), then it will indicate failure, since the product is either making a loss or a very low profit from each unit. The implications of failure for this criterion would be potential cash flow and future investment difficulties.	5
Customer satisfaction	Since the product and its interface is designed to be used with non-skilled and expert users with varying level of abilities, user satisfaction is an indicator of success. This can be in the form of surveys, focus groups or feedback portals. Strong reviews and approval means success for the company, with sales potentially increasing as a result. If the reviews and feedback is poor due to factors surrounding the product (reliability, design, ease of use), this can be damaging to Doble since a poorly received product may tarnish its reputation and may devalue the company as a whole, potentially impacting sales in other areas.	3
Reliability	Is the product able to perform under all conditions over its lifespan without failing in some way? This is an important criteria due to the operating conditions that the product will be in. Success would be the lowest possible number of defective products returned to Doble from customers. Ideally this value should match, or better, the current number of defective returns of the current product. This could increase the number of sales, since this impacts on customer satisfaction. If the percentage of defective products is high, this can end up being costly to both Doble and the customer and in extreme cases, may even result in a loss of life due to the product not being able to detect PD properly and this could result in failure of substation components as a result. Therefore the cost to customers could potentially be very high as a result of a defective product. For Doble, there would be costs incurred with repairing and replacing the defective products. But the consequences are further reaching, with defective products lowering customer satisfaction and potentially losing customers as a result, with the company's reputation tarnished and loss of sales meaning loss of profit.	1

Table 15. success and quality criteria

11. ETHICS, LEGAL & SUSTAINABILITY CONSIDERATIONS

Ethics

Some ethical considerations have to be taken into account, in accordance to the values of the company. It is a high quality company, that basically sells knowledge and services. Doble has an active role in the industry in research and standards, with the company investing in scholarship programs, professional education courses and university grants for research and development.

Manufacture Outsourcing

Some companies take advantage of outsourcing the labour to countries where the personnel is underpaid and work under inhumane conditions to lower the costs of production. Another reason for outsourcing is usually to avoid environmental standards, that are applied in their home countries.

Doble does outsource labour to other countries, but has minimum standards that need to be present, like fair wages and working in good conditions. As it is a reputable company, it has to maintain the standards of the product's components and materials in order to meet legal requirements around the globe.

Conflict Materials

This term is used when the natural resources from countries that are in conflict are sold by armed groups to in order to buy supplies. By buying that material the company would be helping to perpetuate the war. Some of this minerals are: cassiterite, wolframite, coltan and gold, which are extracted from the Democratic Republic of Congo, as they have some of the world's biggest reserves.

It is quite difficult to avoid, as normally it goes through various intermediaries before being purchased by international companies, but is worthy looking at it from an ethical point of view.

Responsible Marketing

Ethics applied to marketing is important, as the product cannot advertise features that does not have to make money. In this case this could be even more harmful, as the image of the company could be damaged. Doble is a company that has a reputation to maintain in its field and bad reviews due to an irresponsible marketing campaign could develop in a loss of clients.

For that reason the marketing strategy developed in this reports follows the principles of ethical marketing, which are:

- Promotion of honesty
- It is fair for customers to know the true nature of the product.
- The privacy of the consumer must not be compromised by any means.
- Responsibility.

Safety in substations

In case of imminent danger in the area being under surveillance, the product would show a high peak to average power ratio and suggest the user to rapidly leave the area, then the user has to warn the pertinent authority and other colleagues that may be present, to take the adequate measurements.

Legal considerations

Manufacturers have to adhere to regulations and standards, that the product must follow before it can be sold. These requirements need to be checked as they rapidly change following technological developments. The main areas in which this issue can be applied to the product are: CE standards, more in particular EMC, and technical safety as the user will be working in a high voltage area.

Technical safety

The product operates in a high voltage environment; therefore, it requires to meet certain safety requirements for making it secure to operate.

· Lithium-ion batteries on planes

The product uses Lithium-ion batteries that are 'a secondary (rechargeable) battery where the lithium is only present in an ionic form in the electrolyte. Also included within the category of lithium-ion batteries are lithium polymer batteries. Lithium-ion batteries are generally used to power devices such as mobile telephones, laptop computers, tablets, power tools and e-bikes.' (Iataorg, 2017).

Figure 69. Lithium batteries (Iataorg, 2017)

The kind of batteries used in the product are medium lithium-ion. They have certain restrictions in planes if they surpass a certain power per hour. Whether they can be carried by air or not depends on the Watt-hour (Wh) if they are rechargeable, or Lithium Content (LC) if they are non-rechargeable.

First, calculation of the total power per hour (Wh) in the product is required, as all the batteries used are rechargeable. It is calculated using the nominal voltage.

Tablet Getac Z710-Ex
7.600 mAh×3,7 V=28,12 Wh

Tablet Mitac Ulmo
4.000 mAh×3,7 V=14,80 Wh

External battery Lumsig Harmonica
10.400 mAh×3,7 V=38,48 Wh

Total Watt-hour in the product using tablet Getac Z710-Ex:
38,48+28,12=66,60 Wh

Total Watt-hour in the product using tablet Mitac Ulmo:
38,48+14,80=53,28 Wh

To determine if the product battery is acceptable, the following Table is used.

Watt Hour Rating (Wh) or (Li Content)	Configuration	Carry-on Baggage	Checked Baggage	Operator Approval
≤100 Wh (2g)	In Equipment	Yes	Yes	No
	Spares	Yes (No Limit)	No	
>100 to ≤160 Wh	In Equipment	Yes	Yes	Yes
	Spares	Yes (Max 2)	No	
>160 Wh	Must be presented and carried as Cargo in accordance with the IATA Dangerous Goods Regulations			

Table 16. Accepted lithium battery rates in airplanes

The product is inside the category below 100 Wh, so the user should not have any problems with transporting the device by airplane.

For more information about lithium batteries in airplanes, the 2017 Lithium Battery Guidance Document can be read.

· **ATEX**

The ATEX directive regulates which equipment is adequate for working in an explosive atmosphere. It is based in the French 94/9/EC directive.

The regulations are applied to equipment intended to use in explosive atmospheres, they may be either electrical or mechanical. There are two main divisions of products, zone 1 for mining and zone 2 for outdoor industries. The producers that apply the CE standards and the ATEX can sell their products within Europe without any other requirements with respect to risks. This directive coverage ranges from equipment used in flour mills to machinery used to fix offshore platforms.

It may be necessary to have the product certified because some of Doble's clients may work in potentially explosive atmospheres, the substations itself can be seen as one, so without it the company might lose possible customers.

An explosive atmosphere from the point of view of the directive 94/9/EC is defined as:
- Mixture of flammable substances in form of gases, dusts, mists and vapours
- With air
- Under extreme atmospheric conditions, commonly referred as temperatures of -20 ˚C to 50 ˚C and pressures from 0,8 to 1,1 bar.
- In which after the ignition, the combustion spreads

The products covered by the directive are equipment, protective systems, components and safety controlling or regulating devices. The product is suited to certain categories.

Adding the certificate to the product provides an assurance that the equipment being sold will not cause an explosion, which will put personnel and expensive equipment in danger, and that the production meets a certain standard of quality.

For more information, see Atex guidelines.

CE Standards
The CE mark is a mandatory mark for certain products to be sold within the European Union and proves that it follows the EU safety, environmental protection legislation and safety. All the electronic parts of the product must follow CE guidelines.

It is known that the Red Pitaya company has all their products marked by CE, meaning that they fulfill its standards. The same happens with the companies MiTac, that sells the Ulmo tablet, and Ulmsig Harmonic, that sells the battery.

As for the tablet Getac Z710-Ex: 'As a general rule New Approach directives including Directive 94/9/EC provide for the affixing of the CE marking as part of the conformity assessment procedures in the perspective of total harmonisation. The conformity assessment procedures to be applied are described in the relevant New Approach directives, based on the conformity assessment procedures as defined by Council Decision 93/465/EEC. Where a product is subject to several directives, which all provide for the affixing of CE marking, the marking indicates that the product is presumed to conform to the provisions of all these directives.' (Atex, 2017)

- **EMC standards**

The product electronics must be in compliance on a few EMC (Electromagnetic Compatibility) standards, these attempt to standardize the performance of electrical devices in respect to radio interference. The regulations applied to the product are:
- EN 61000-6-2:2005
- EN 61326-1:2013
- CISPR 11
- CISPR 16-2

Sustainability

Consideration of sustainability is a key part in ensuring that the product is be to be developed, manufactured and sold ethically and morally. A sustainable approach should be considered for the lifecycle of the entire product. A table of key sustainability considerations that should be taken into account for the product is shown, with details of how the product deals with this aspect and what further work is required

Sustainable consideration	Description	Conclusion/issues
Recycling	The product should be manufactured from a material that can be processed at the end of the product's life cycle, allowing it to be reused for other purposes. The product could also be manufactured from recycled materials.	The tablet holder is manufactured from ABS plastic, which is recyclable since it is a thermoplastic. The other aspects of the product are bought directly from suppliers and therefore there may be parts/ components that are not recyclable. This would need further reviewing to locate.
Green technology	This encompasses the entire life cycle of the product and applies to any aspect of the product that will minimise environmental damage. This can apply to manufacturing methods, technologies, transportation and use of the product.	The product utilises green technology in terms of recyclability and using a manufacturing process that may be powered by renewable sources. The use of the device may also be powered by energy from renewable resources. But this could be reviewed and improved by using environmentally preferred purchasing to reduce the number of parts that are not environmentally friendly, and in the manufacturing process, maximise the quantity of waste produce that can be reused for other applications.

Sustainable consideration	Description	Conclusion/issues
Renewable	If possible, the product should be made from sources that are renewable, such as the materials that it is manufactured from. This can also apply to the energy that the product uses for its manufacturing, transportation and if it requires energy, should be powered from renewable sources such as wind, tidal or solar power.	There are no components that are renewable, and the only part of the product's entire lifecycle that is renewable is that the energy used to power it can come from a renewable source of energy. In order to further utilise renewable resources in this product, further investigation into material and component selection would be required.
Conflict materials	If possible, the materials or the manufacturing of the product should not be done in geographical areas of conflict, or in areas where resources sold to be used in the product will be used to directly fund conflicts.	The majority of the product is manufactured from types of plastics, which has oil as a raw material. Currently, there are conflicts in the world in locations where there are oil fields such as in South Sudan, where oil sales are being used to fund a civil war (Global Witness, 2017). To prevent this, suppliers should be consulted with to ensure that there is no conflict materials in the product.

Table 17. Key sustainability considerations

In order to ensure that the product has adhered to a sustainable approach, it may need to meet the following environmental standards:

- Restriction of the Use of Certain Hazardous Substances (RoHS) directive 2002/95/EC regarding hazardous substances in electrical parts. Directive 2008/98/EC is also used in regards to waste management and prevention.
- WEEE Directive 2002/96/EC regarding waste from electronics and electrical components.
- ISO 1400 standards regarding environmental management of the product's life cycle.

This would ensure that the product's environmental and sustainability performance regarding its entire lifecycle is acceptable.

12. CONCLUSIONS / RECOMMENDATIONS

The challenge of this project consisted a new design of the PDS100, using disruptive technologies and meetings today's standards of human-interaction, usability and high technologies, without loosing its actual accuracy and functionality.

The product designed in this project meets Doble's objectives of having an innovating view on how a partial discharge detector could look like, being different from the actual device and any of its competitors in the market.

By dividing the product into three parts, the product will be more comfortable in terms of wearing it a whole working day. The heavier parts, such as the battery, are secured in the backpack device. Moreover, as the tablet is worn on the forearm with a wearable, both hands are free. This makes it possible to include a handheld antenna when frequency scans are needed. When the user is walking and the antenna is not required, it can be stored in the backpack device.

Apart from being comfortable, the device meets the requirement for being used in substations all around the world, no matter the weather conditions. The product can easily be combined with the mandatory safety clothes, without disturbing their secure features. The backpack device is not only chosen because of the hardware fitting inside it, but also because it is waterproof and adaptable to the user on many levels. It can be used as a shoulder bag or a waist belt. The waist belt on his turn has a wide range of sizes and the user can decide how many pockets he needs for the surveillance and his personal belongings. The tablet, used for the new designed interface, is highly robust and has a rugged design, so even if it falls it would not break. Beside this, the tablet is water and dust proof, therefore the user is able to work indoor and outdoor no matter the weather condition. The tactile screen can tolerate the user working with safety gloves, even the heavy ones.

For the application and the data management some new technologies have been adopted in order to improve the product. A major enhancing is the device being cloud based, with easy access to the data taken in past surveillances as well as an easy saving system of the new measurements also into the cloud. Another improvement is the location in the substations. Two independent views of the map have been included to easily know where the user is located inside the substation. The first view is a 2D map with a outlined path for old and new measurements. The other view is a instantly real view from the camera combined with augmented reality to show the taken or the to undertake measurements. In order to accurately locate both the user and the measurements in the map, the GPS chip of the tablet is used. For more precision, there is the option of acquiring a DGPS receiver which will improve the accuracy to a sub-meter level.

In order to make the device suitable for unskilled technicians/ engineers, a simpler version of the existing graphs, showing the results of the measurements, has been created, without loosing the option of more advanced results. An easy way of comparing results of previous measurements in order to easily see the evolution of the partial discharge at one point has been added too, making trending possible.

Due to limitations in the existing location technologies, a robust working solution for indoor environments is not included. Future R&D in this field has to be focused on pseudolites, as this technology can solve the main limitation of this product, a precise location for indoor. Further investigation in 3D mapping technologies is also required, as it could be interesting to create 3D models of the substations while taking the measurements. This could be used by the companies for many different purposes.

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14. APPENDICES

Appendix A – RADIO FREQUENCY INTERFERENCE

When partial discharge takes place in the insulations, the spark produced emits radio frequency waves that are spread around in the surrounding media. This phenomenon is similar to the sound of a bell and what is heard in the distance are the resonant harmonics. These radio frequency signals weaken and disperse with the distance, and that is why when using the PDS100 the user has to be near the PD origin in order to detect it. The antenna is used to improve the detection of RF and make it easier to find the problem.

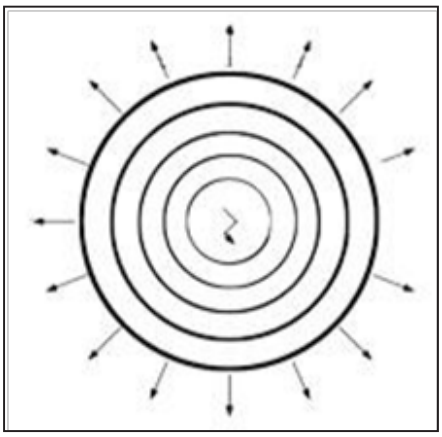


Figure 1. Representation of RFI propagation from the discharge source

The representation of the radio frequency detected is as shown in the Figure 2. The whole spectrum is represented at once, and the amplitude is measured in dB. In the figure, the black signal represents the baseline taken outside the substation and the red one is the radio frequency detected during the surveillance.

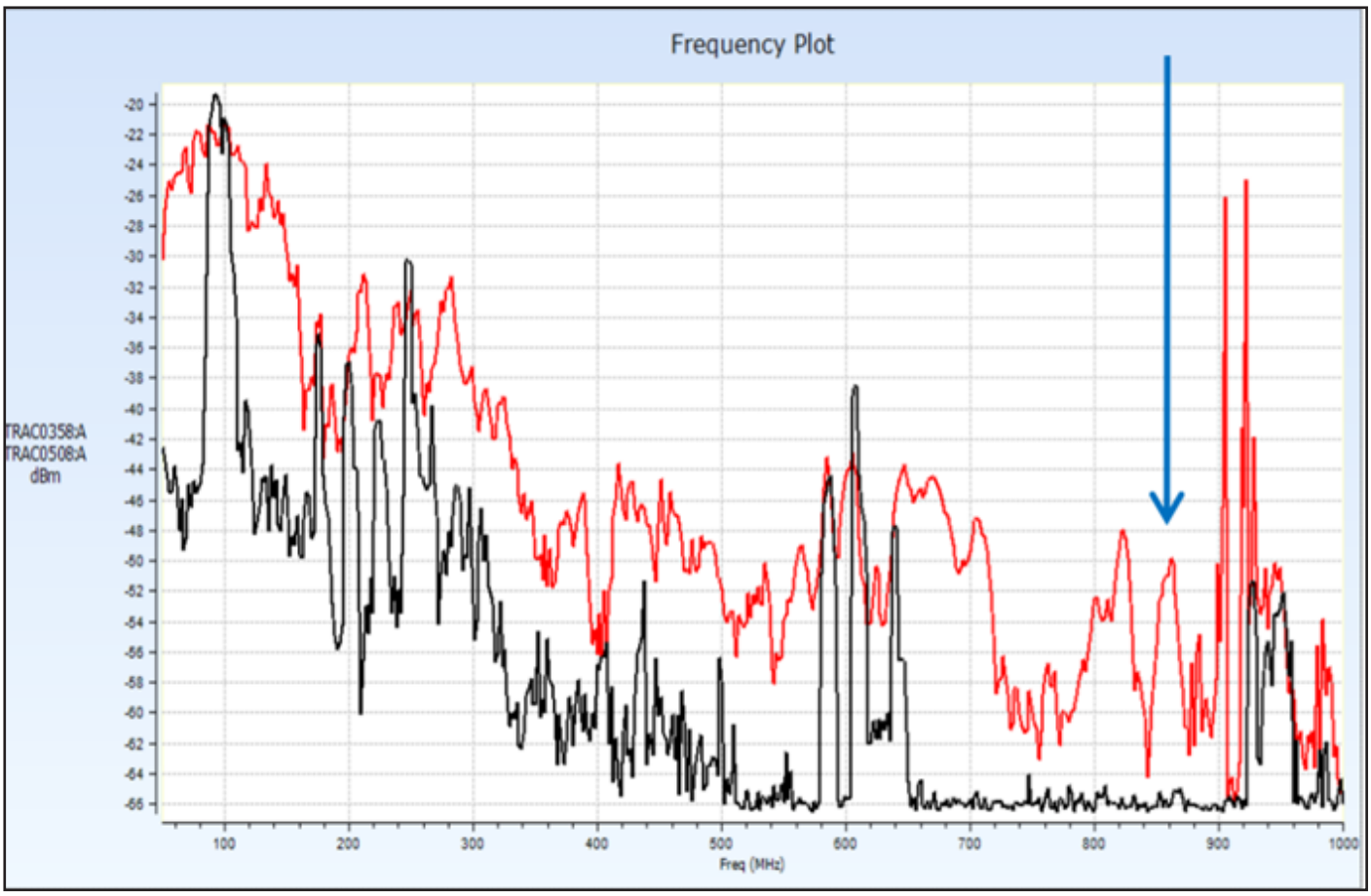


Figure 2. Representation of what the RF measurement looks like.

Appendix B – DATA SHEET OF PDS 100

CHECK IN-SERVICE SUBSTATION EQUIPMENT FOR SIGNS OF INTERNAL INSULATION DAMAGE

The Doble PDS100 Partial Discharge Surveyor is an RFI surveying tool that is designed for use in a live substation. Without the need for outages, the PDS100 can detect partial discharge (PD) in just a few seconds, thus making it an ideal tool for a condition based maintenance program. Whole substations can be quickly surveyed and analyzed.

FEATURES

- Uses RFI technology to identify and locate defects
- Rugged, light-weight, hand-held instrument
- Works with a variety of sensors, probes and antennae for various applications

BENEFITS

- Safe and effective method for PD detection
- Non-invasive inspection method for substation surveys
- Use on a daily basis or during routine substation inspections together with other methods such as infrared scanning

PDS100 TECHNICAL SPECIFICATIONS

POWER SUPPLY	
External supply	External DC adaptor, 12 V @ 2 A
DC adapter	85 - 264 V AC (47 - 63 Hz)/ 12 V DC
Internal battery	Li-Ion, 7.2 V, 6.6 Ah
Battery life	> 4 hours
DETECTION AND SWEEP FUNCTIONS	
Detector modes	Peak, Average and Separate Peak and Average Mode(SPAM)
Sweep modes	Continuous, Counted and Single Mode
FREQUENCY	
Measurement range	50 MHz - 1000 MHz
AMPLITUDE	
Display unit	X/Y-axis: ms - MHz / dBm
DATA STORAGE/ TRANSFER	
Internal	SD-Card (fixed)
External	USB storage class compliant, including Memory stick
Data Transfer	USB A/B to and from computer
LCD SCREEN	
Size	132 x 100 mm / 5.20 x 3.94 in (W x H)
Resolution	640 x 480 pixels, 256 colors
MECHANICAL	
Size	350 x 220 x 70 mm / 8.85 x 12.20 x 2.25 in (WxHxD)
Weight	2.2 kg / 4.85 lbs
ENVIRONMENT	
IP classification	IP64 with top covers closed IP51 with top covers open
Humidity	0 - 95% non-condensing
Operating temperature	0°C to + 50°C / 14°F to 122°F
Storage temperature	-20°C to + 70°C / -4°F to 158°F

USER-FRIENDLY

The PDS100 is a rugged, light-weight and powerful high-tech instrument with a big display and large soft key buttons. The instrument is easy to use and the software enables the operator to record and analyze PD signals and make decisions for further actions.

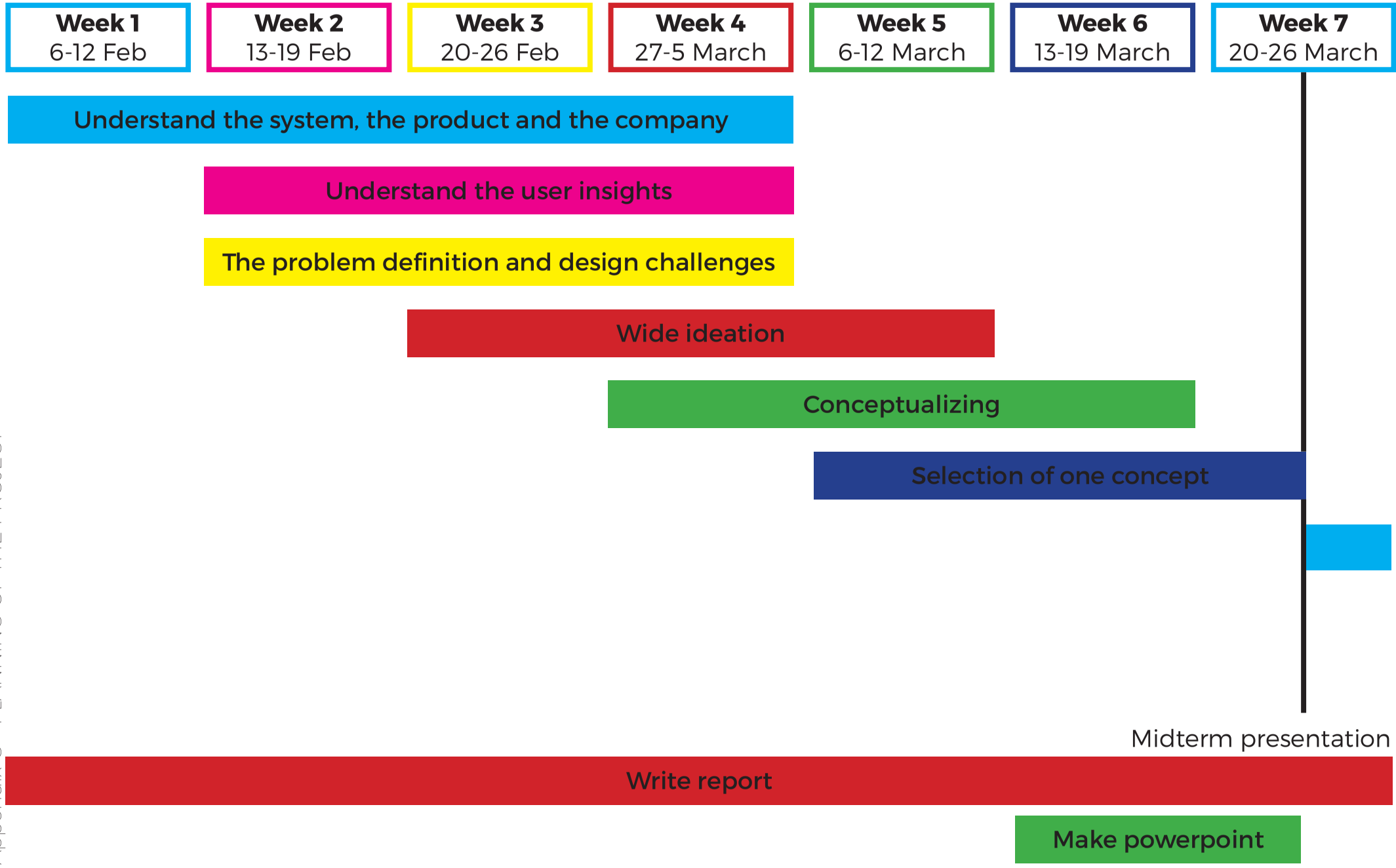
TECHNOLOGY

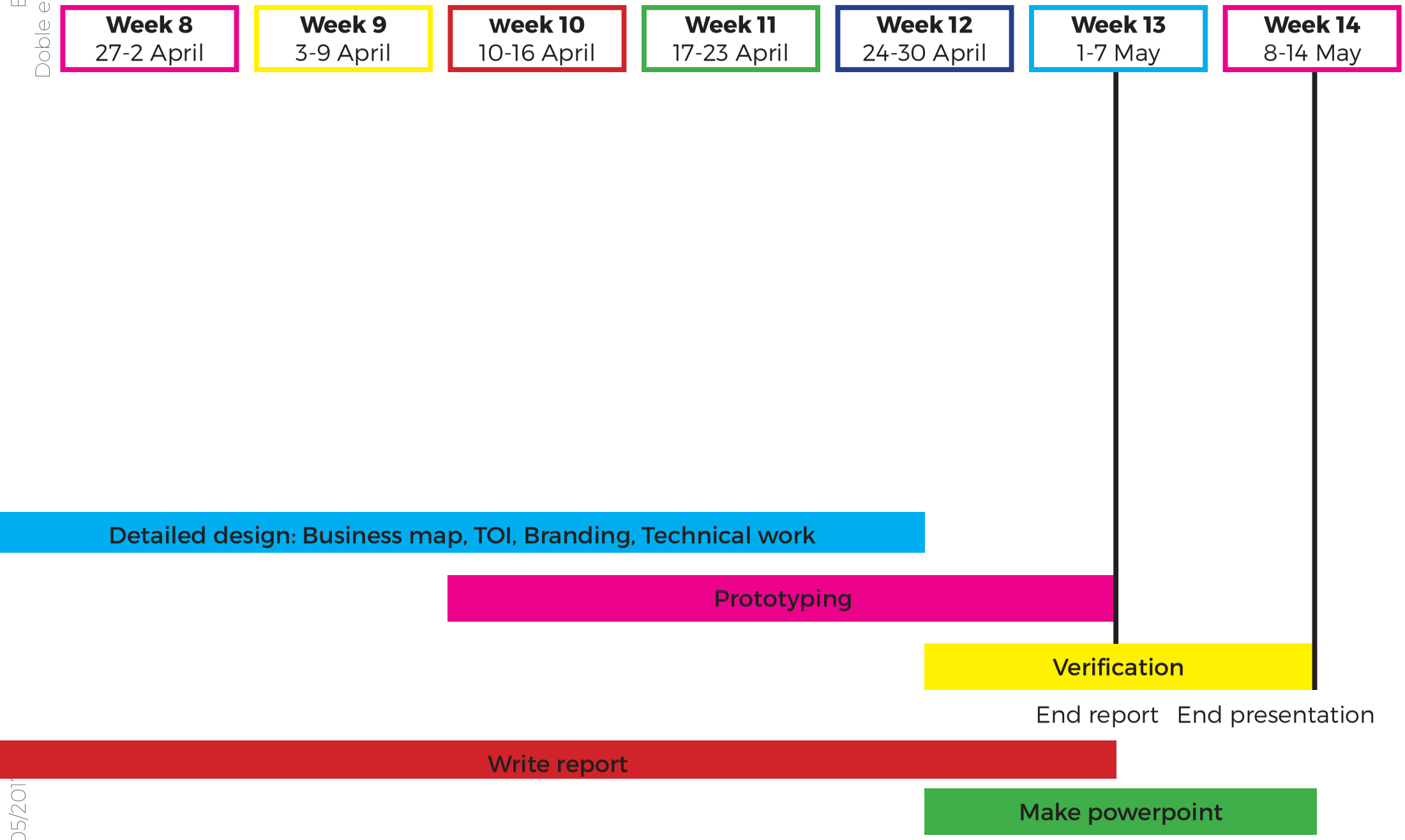
The instrument searches for PD in the radio frequency area. Harmful PD will reveal itself by the electromagnetic energy emitted from the area where the activity is. The PDS100 captures the electromagnetic energy in the RF spectrum and displays a "footprint" of the RF interference from partial discharge causing the radiation.

ORDERING INFORMATION

PART #	PRODUCT
TN-80000	PDS100: Complete with Case, Antenna, Adapter and PC software
	ACCESSORIES
	A variety of sensors, probes, and antennae are available for various applications

The projectplanning




Week 8
27-2 April
Week 9
3-9 April
week 10
10-16 April
Week 11
17-23 April
Week 12
24-30 April
Week 13
1-7 May
Week 14
8-14 May
Detailed design: Business map, TOI, Branding, Technical work
Prototyping
Verification
End report
End presentation
Write report
Make powerpoint

Appendix D – COMPETITORS

HVPD

HVPD was founded in 2006 and supply online partial discharge surveying and diagnostic equipment and services across 100 countries (Hvpd.co.uk, 2017).
HVPD have a portable unit, the PDS Insight, which is a handheld partial discharge test unit designed to test outdoor high voltage switchyards.

Figure 3. PDS Insight with tablet application (Hvpd.co.uk, 2017. HVPD PDS Insight™)

The PDS Insight has a basic interface and only has directional and confirmation buttons. This is because the data gathered by the device is stored and is then displayed via a tablet running an Android operating system. The data is displayed and analysed through a specialised app. The data is transferred from the device to the tablet via Bluetooth (Hvpd.co.uk, 2017. HVPD PDS Insight™). The Insight uses 3 PD sensors, TEV (Transient Earth Discharge), AA (Airborne Acoustic) and HFCT (High Frequency Current Transformer) sensors, that can be used with an optional handheld antenna. It has the following features (Hvpd.co.uk, 2017):

- Polycarbonate ABS/TBE casing
- IP 54 classification
- 3.5” 320x240 LCD display
- Lithium ion battery
- Run time of approximately 8 hours
- BNC, LEMO, USB micro B
- Barcode reader for asset location identification
- Headphones can be used for acoustic signals

The tablet application can display partial discharge levels, trending graphs and storing details of cables under test alongside measurement and site (Hvpd.co.uk, 2017).

EA Technology

Founded in 1966, EA technology specialises in products and services for power asset monitoring in areas such as electricity transmission, transport infrastructure, mining and process engineering (EA Technology, 2017). The UltraTEV Locater is EA technology’s portable PD monitoring device.

Figure 4. UltraTEV Locator (EA Technology, 2017)

The UltraTEV uses handheld antennas connected to a portable unit which can measure and record PD using ultrasonic and TEV sensors. The device has a weatherproof, IP42 casing and is capable of measuring air pressure, humidity and temperature via a probe attachment (EA Technology, 2017). The device interface is via a high-resolution touchscreen which can be used while the device is in its carrying case and displays reading and analysis (EA Technology, 2017). The stored measurement files can be navigated using the touchscreen. The UltraTEV has a 3.7V, 27.2Ah battery that allows the device to run for up to 13 hours and has a wide range of connectors such as a LEMO socket, 3.5mm jack, 2.1mm DC battery charger and a USB 1.1 type A port that allows data transfer from the device to a PC and allows for software updates (EA Technology, 2017). The headphone jack allows audio analysis of PD with neckband headphones that are included with the UltraTEV.

Megger

Megger has been running for over 100 years and manufacture equipment for testing and maintenance of electrical assets in the UK, USA, Germany and Sweden (Uk.megger.com, 2017). Their unit for handheld testing in MV/HV substations is the UHF PD detector.

Figure 5. UHF PD detector (En.megger.com, 2017)

The main feature of the UHF PD's design is the 6-inch touchscreen interface which can show PD readings/analysis but the device can be operated using a foil keypad (En.megger.com, 2017). The device measures PD using two-phase (RF and UHF) measurements with TEV and HFCT sensors via a di-pole antenna and can filter out noise signals from the PD signal using a Phase Resolved PD (PRPD) display (En.megger.com, 2017). The inbuilt battery is a 7.4V, 12.25Ah lithium ion battery which has a run time of 10 hours and a charge time of 6 hours. The PD test data is stored via 10Gb of internal memory and can be transferred to a PC with a USB 2.0 output (Global.megger.com, 2017). The device has an IP65 rating, which is increased to IP67 when inside its 3.8kg transport case with the device weighing 1.9kg (Global.megger.com, 2017).

Qualitrol

Founded in 1945, Qualitrol specialise in measurement and monitoring equipment for power generation and transmission. Their portable PD product is the portable PDM transformer and GIS Partial Discharge monitor.

Figure 6. Qualitrol portable PDM/GIS partial discharge monitor (Qualitrolcorp.com, 2017)

The Qualitrol unit contains the following features (Qualitrolcorp.com, 2017):

- All components are stored in a wheeled case with IP66 rating
- User interface is a large, 12-inch touchscreen
- PD is detected using UHF across 300-1500MHz range
- Connects to sensors fitted to measurement location or an optional antenna is used
- Software supplied will automatically log and alarm faults and can trend PD measurements
- Ability to detect multiple PD sources simultaneously
- 16Gb internal memory that can be used for back up with USB

The wheeled storage case means it has good portability despite its size, but requires a power source since there is no internal battery.

BAUR

BAUR is a German company that was founded in 1945 and manufacture service and maintenance products for electrical transmission systems. The BAUR PD-SGS is their portable PD detection device.

Figure 7. BAUR PD-SGS (Baur.at, 2017)

The PD-SGS is a handheld device and has a simple interface, with 2 buttons and a small screen that shows basic information. Its key features are (Baur.at, 2017):

- TEV and acoustic sensors
- LED acoustic indicators
- 3.5mm jack means it can be used with headphones
- Can display real time signals or a 5-second trend
- Rechargeable lithium ion battery
- IP54 protection
- Stored in transport case

The LED indicators are designed to give an indication of partial discharge strength, providing a quick visual indication. The unit is lightweight and is designed for detection, but no detailed analysis can be done with the data since the device has no internal memory.

Techimp

Techimp is an Italian manufacturer of diagnostic and service equipment for electrical assets. The Aquila is Techimp's portable PD monitoring system. The device and its components are all stored inside its transport case.

Figure 8. Techimp Aquila (Techimp.com, 2017)

The Aquila has the following features (Techimp.com, 2017):
- Embedded 11-inch industrial tablet for data viewing and analysis
- Designed to be used with all assets
- Wi-Fi, fibre optic, USB and Bluetooth connectivity
- User friendly software for automatic testing/reporting
- 20-hour battery life

The large display allows detection and analysis to be done on site and can also be done on PC software with USB outputs.

Ndb

Ndb have been designing and manufacturing test equipment for electrical assets for over 20 years and have a range of fixed and portable PD monitoring devices that are used globally. Their portable PD monitoring device is the XDP-2.

Figure 9. Ndb XDP-2 (Ndbtech.com, 2017)

This device is designed to be used with a range of accessories and its features include (Ndbtech.com, 2017):
- Use for MV and HV sources via TEV or acoustic sensors
- In-built speaker plays sound reproduction of PD
- LCD display displays readings
- User input via 6 buttons
- Data is stored in internal memory and then analysed via PC software
- Casing is splash-proof
- Measurements require probe to be in contact with location of measurement

The device has a small screen that only shows basic information but headphones are not required for this device due to speakers.

Sonotec

Sonotec is a German company that specialises in using ultrasound technology in products for medical, mechanical, chemical and electrical applications. Their product for detecting partial discharge is the Sonaphone.

Figure 10. Sonotec Sonaphone (Sonotec.eu, 2017)

The Sonaphone detects partial discharge using ultrasound technology. Its main features are (Sonotec.eu, 2017):
- 20-100kHz range
- 5 inch TFT touchscreen display with multi-touch controller
- Acoustic output via speakers or headphones
- Handheld acoustic sensor includes a volume control and target laser and can be operated from Sonaphone
- IP40 rating
- 16Gb memory with Micro-SD slot means data can be transferred to PC for analysis
- Battery life of 8-12 hours

Sonotec also have a more compact device designed to do the same purpose, the Sonaphone pocket. This is a simplified version of the Sonaphone with a smaller display that has a simpler user interface.

Figure 11. Sonaphone pocket (Sonatec.eu, 2017)

It has the following features:
- Can be used with a wide range of accessories
- Acoustic signals heard via headphones
- Powered by 2 AA batteries, with an operating lifespan of 24 hours
- IP54 rating
- No memory storage or diagnostic applications; only shows real-time data

PMDT

Power Monitoring and Diagnostics Technology (PMDT) provide services and products for partial discharge monitoring and have a portable detection system, the PDetector.

Figure 12. PMDT PDetector (Partial Discharge - Power Monitoring and Diagnostic Technology, 2017)

The PDetector can be used to detect PD in power cables, substations, switchgears and transformers. The device has the following features (Partial Discharge - Power Monitoring and Diagnostic Technology, 2017):

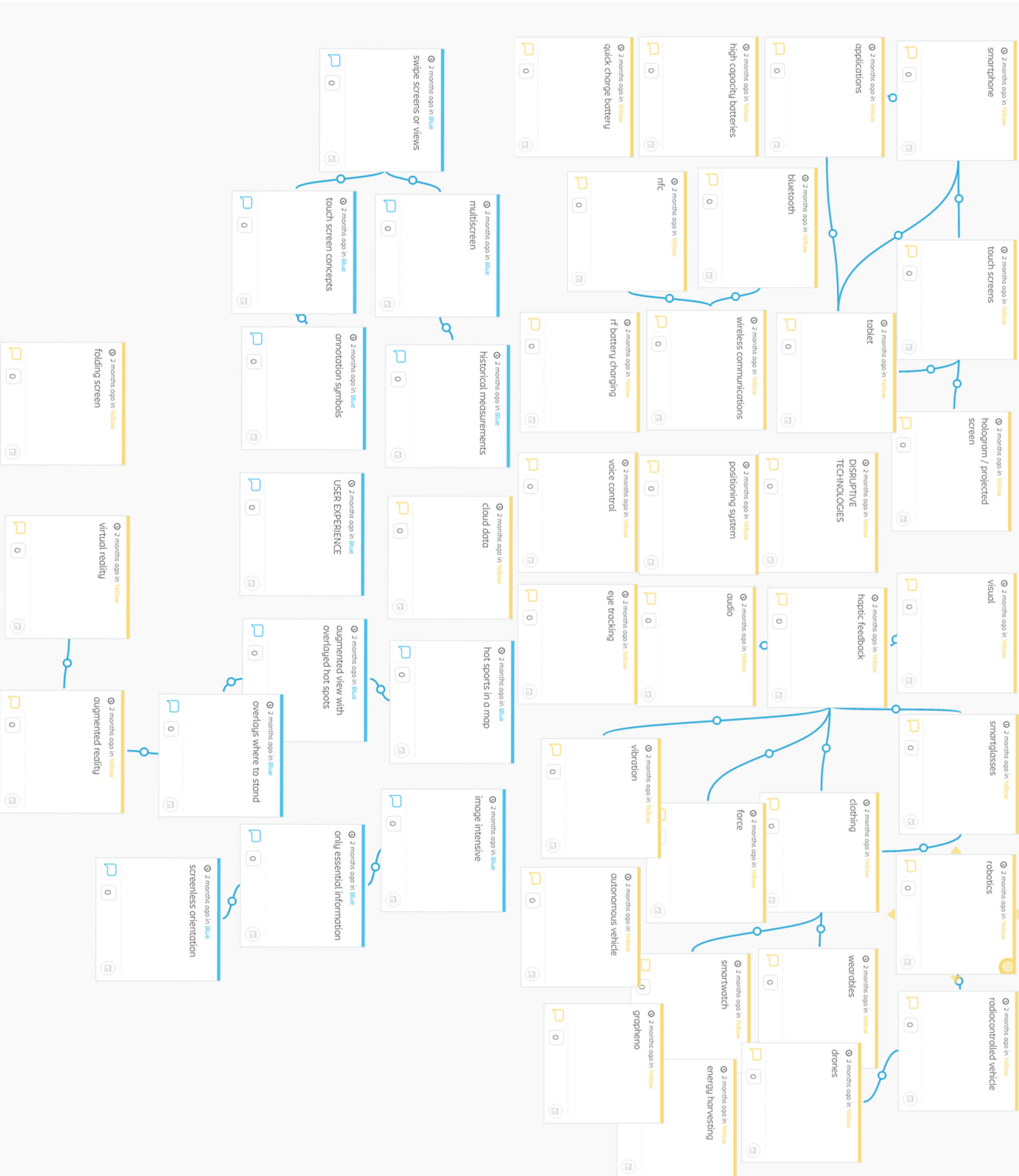
- Detects PD using electromagnetic or acoustic ultrasonic sensors
- Analysis with specialised PC software
- Location of assets can be detected with the use of RFID (Radio Frequency Identification) tags

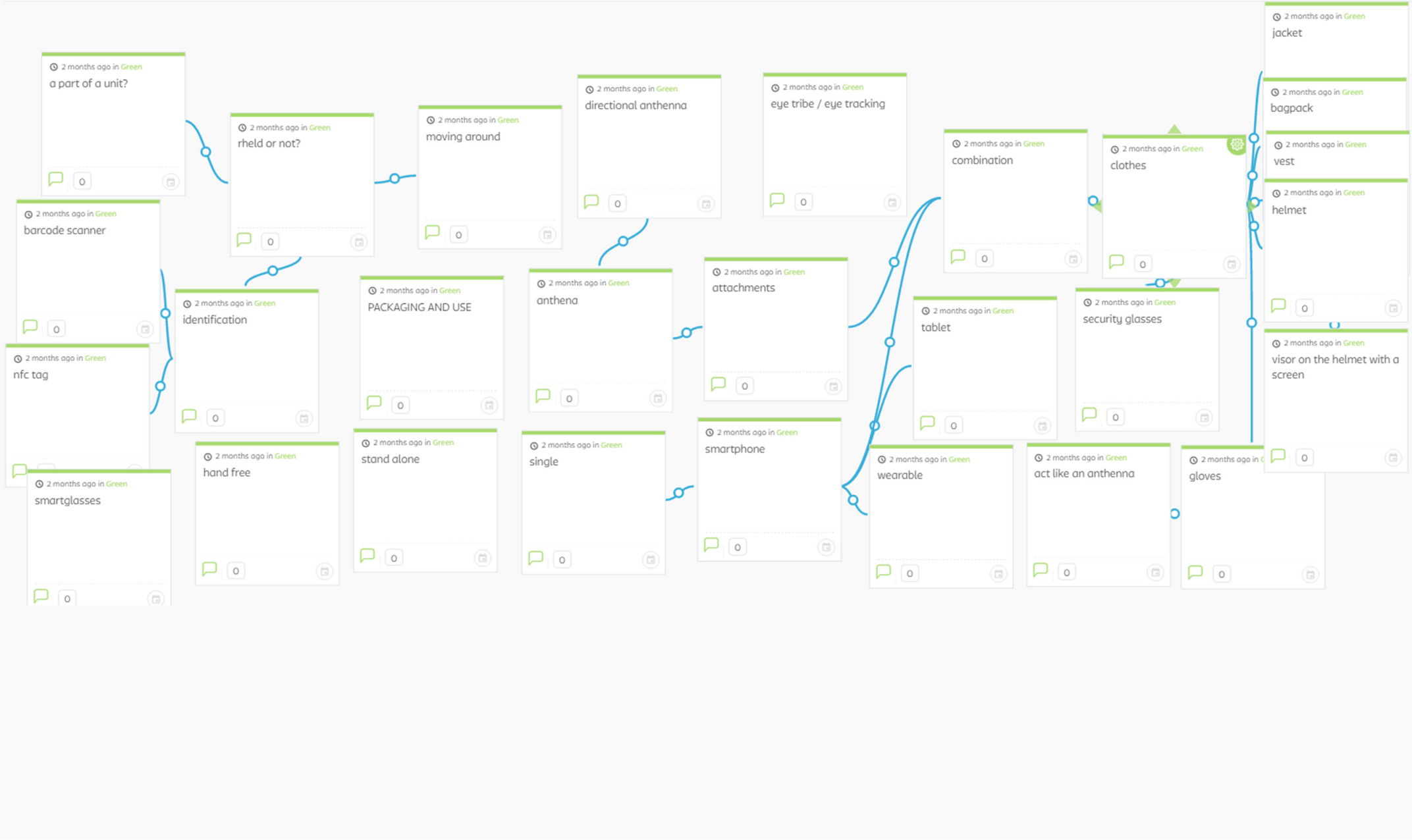
In order to detect airborne acoustic signals, a handheld ultrasonic dish needs to be connected to the PDetector.

Figure 13. Handheld acoustic dish for PDetector (Partial Discharge - Power Monitoring and Diagnostic Technology, 2017)

This means that during operation the user will not have free hands but the handheld dish means that greater accuracy in detecting PD is possible due to the mobility it offers.

Appendix E – BRAINSTORM - MINDMAP

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rheld or not?
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identification
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hand free
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moving around
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PACKAGING AND USE
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stand alone
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combination
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tablet
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wearable
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security glasses
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gloves
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2 months ago in Green
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bagpack
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helmet
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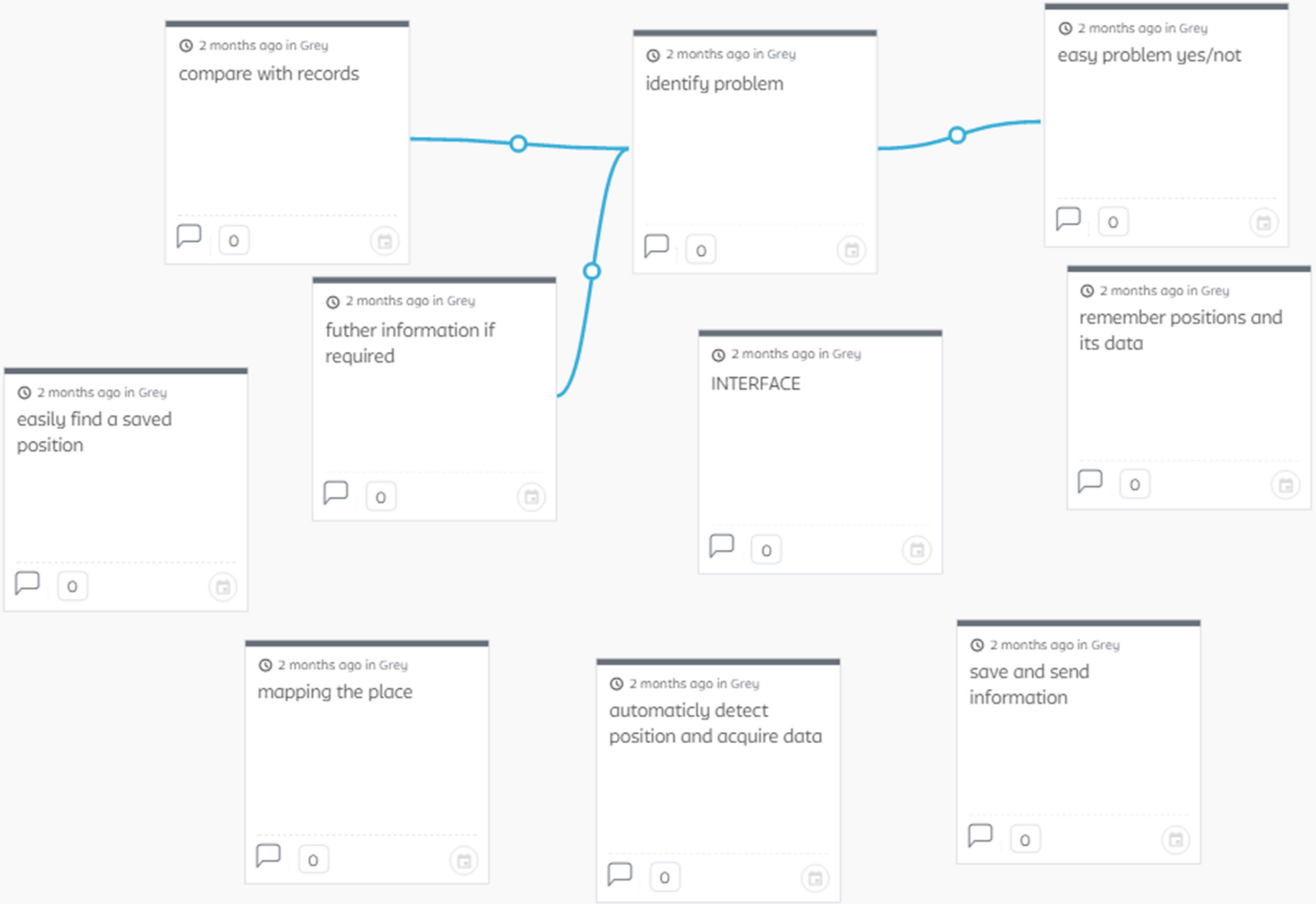
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futher information if required
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2 months ago in Grey
easily find a saved position
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2 months ago in Grey
INTERFACE
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2 months ago in Grey
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mapping the place
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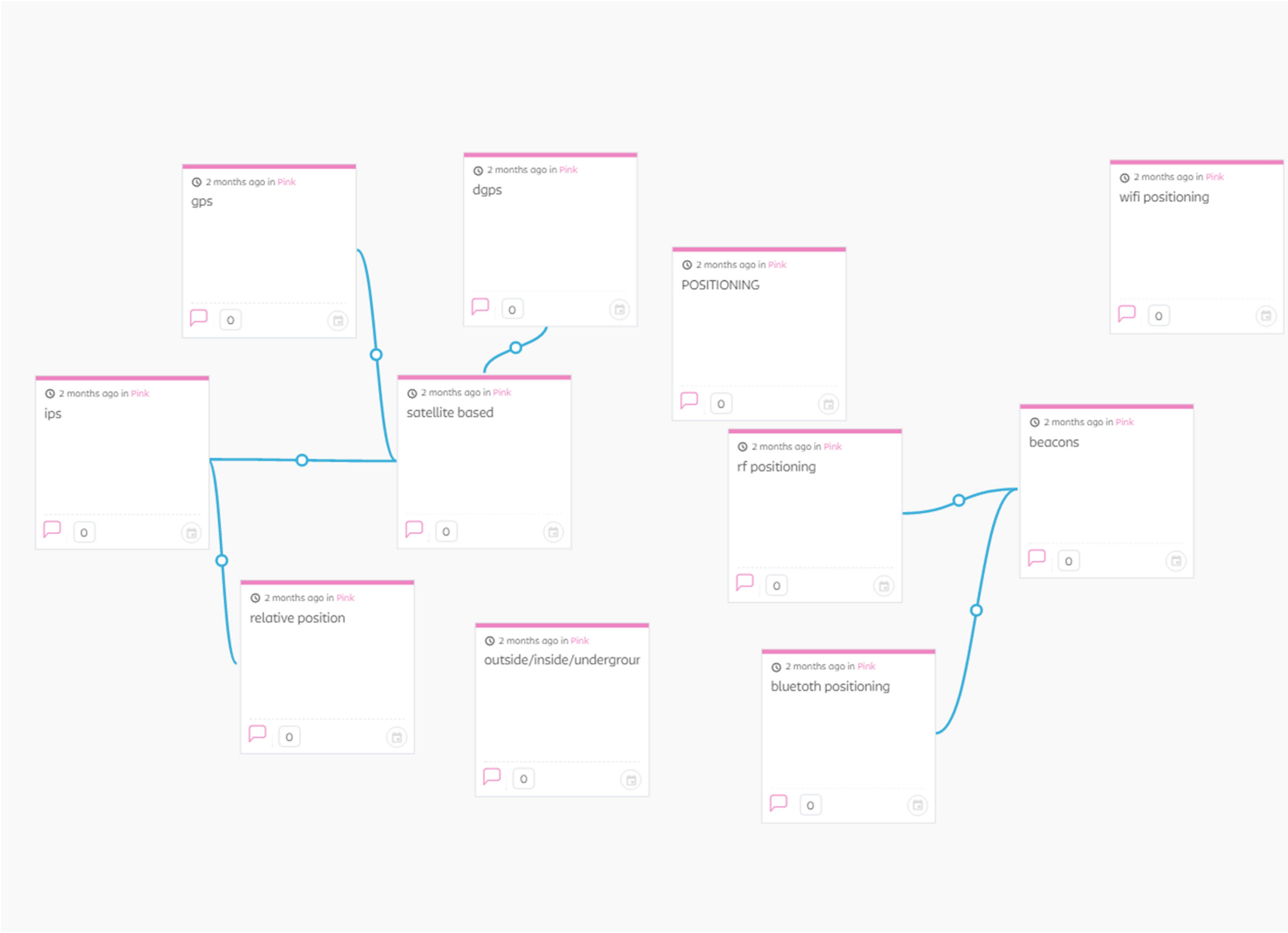
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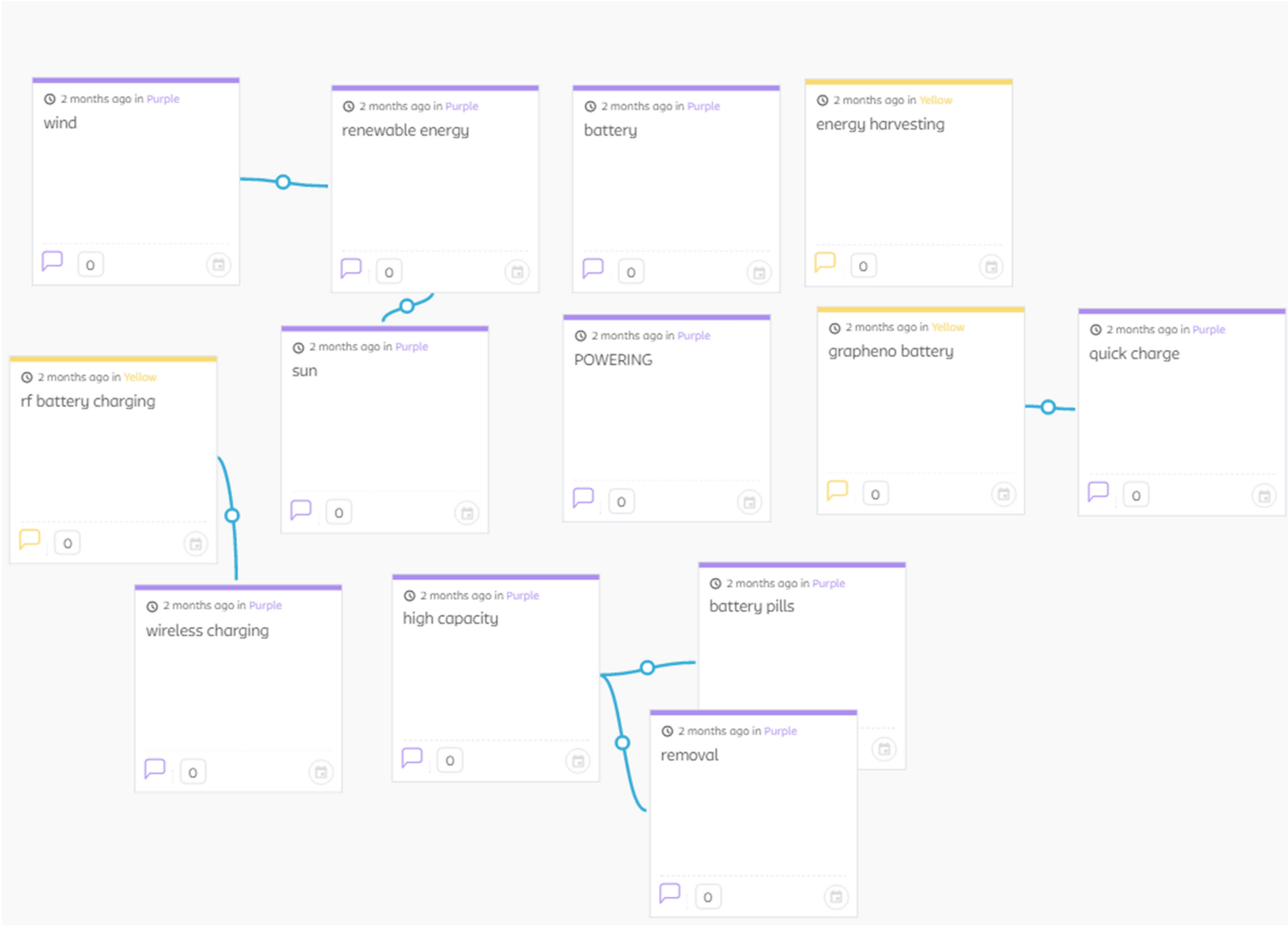
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sun
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POWERING
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high capacity
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battery pills
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removal
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Appendix F – CONCEPTS

Concept 1
Description:
Concept one is about using the safety clothes from the user. Using the safety clothes as a tool to attach the product or use them as a way of showing the results. The goggles, the ear protector, the safety helmets, the gloves or even the clothes can be used to attach product parts, or be used as a product part itself.
Instead of a screen, the safety goggles could be transformed in smart goggles, that way the user could see graphs, maps and information of the substation, PD on the screen before his eyes and the substation at the same time, in addition they can be connected to the Wi-Fi, that could be a big advantage to upload the data at the same moment and compare the actual state with past ones. This could be mixed with some 'virtual reality' views and options. The gloves could be used as antenna. This could make it easier to point the antenna in a good direction. Gloves could also be very important restriction if we want to use a screen or buttons, either the screen or the gloves shall be adapted to work with one another. The ear protector can be used for giving directions and point where the problem is, virtual reality can be combined with this feature. The safety helmet could be used to carry some heavy components of parts from the product. It can also be used as a haptic device that brings you to the good place in the substations by vibration or force.

Figure 14. Smart goggles

Figure 15. Gloves used as an antenna

Advantages
• The user has to wear the clothes, so they are there already.
• The goggles: There are a lot of possibilities by adding smart glasses into the product. Virtual or augmented reality is a good and easy way of showing PD and the map of the substation.
• The gloves: The antenna is not in the way. The antenna is easy to point.
• The ear protection: It can strengthen the way of showing problems and guide the user to them, even without screen.
• The helmet: It can help to carry the weight or spread the weight over different parts along the body. It can also be used for haptic devices and augmented reality.

Disadvantages
• The clothes have to be cared for keeping the user safe. Bringing other features in safety clothes may cause problems or bring the user in danger. In addition, the clothes may differ in different regions due to changes in regulation.

• The gloves: Making this gloves are a big technical challenge. Using the finger as antenna can be a cause of exhaustion for the user.
• The ear protection: Deaf people can't use this device. Needs to be available in a wide variety of languages.
• The helmet: This product is there to keep the head safe, it could be very dangerous to place components into the helmet. Not much weight can be placed in this part of the body.

Concept 2

Description:

Concept two is about dividing the product in different parts. In this section we divide the heavy components of the product that are necessary in two different parts, the ones that are needed but not used on site and the components that have to show results or must be used on site. In one of the parts, there will be the battery, the software etc. In the other, or part two, there will be a screen, the antenna etc. The user could wear a small backpack on his back or even in front on his stomach. In this backpack the heavy components will be stored. As the antenna is the most used accessory,
it will normally be in the hands of the user, but the other accessories can be easily carried just in case they are needed, making it easier to change from one to another. In front of him the user will have a 'tablet' or a 'smartphone' or another kind of product that can show the results. Wearables could show graphs and results in an easy way. Using wearables is an easy way of adding haptic devices. This way it is achieved to reduce the weight carried in the arms and making the product more user friendly.

Figure 16. Divided product

Figure 17. Smartwatches

Advantages

This can have a lot of advantages, like dividing the weight of the product. There are more manners possible than we visualized and the two examples that we visualized can be more elaborated.
• The user can divide the weight and put it on different places.
• The user can walk easily with the product around the substation.
• The display is clear and has a lot of possibilities.
• The product can be much more ergonomic.
• By using new technologies, the display can be much more elaborated and at the same time easier to understand.

Disadvantages
• The user wear gloves, so the screen has to be practicable.
• The two parts has to be connected in a way.
• The heavy components are not reduced nor eliminated, just moved to a more comfortable place for the user.

Concept 3

Description:

Concept three is about devices that are placed on site, this one could be removeable or not. The measurements are done on site, that means there can be by multiple elements posted on various spots in the field or one big radar.

The elements are measuring all the time and are looking for PD. There is one processor, that needs to be placed in a place with access to internet, and the other elements are just sensors that send the data to the main one using Bluetooth, Wi-Fi or even cables. When a person passes through the elements sees on a basic display if there is any kind of problem because the processor sends them the results of the survey. It is automatic, when it detects a problem or an important change, sends an email or notification to the electric company, that way the user does not have to move around. This solution can also be done with removable elements that can be placed when it is needed.

By placing a big radar in the middle of the substation, it is possible to define problem areas. This could prevent the time the user spends in the substation by reducing it. It can create a map of the most problem areas and compare it with past data. Then send the data to the company.

Figure 18. Sensors placed in each hotspot Figure 19. Radar in the middle of the substation

Advantages

- Doble don't need anybody to go to the substation and make the measurement. This can make it much cheaper for the company.
- The measurements can be analysed much quicker.
- The station is under permanent surveillance.
- The problems will be defined in a faster way.

Disadvantages

- It can be very expensive to make a system that stays all the time in the substation.
- Making more than one product can also be very expensive.
- By placing individual devices before the systems, the user can also lose a lot of time.
- The big radar needs study to see if it is feasible to work in a proper way.
- One of them needs to have access to internet.

Concept 4

Description:

Concept four is all about using robotics to measure the PD in the substation, that way the user would not have to walk into the station anymore. Using robotics can be another way to obtain the desired data with less effort from the user part. By using a remote-controlled drone, the user doesn't have to walk true the substation anymore.

To avoid the danger of cutting cables with a drone, it can be replaced by a vehicle with a remote control or something similar. The device has an antenna, which the user can move with the remote control also and a camera, so that you can control it from a computer, receiving the data at real time. This allows to do surveys in normally inaccessible places and in any weather condition. The computer program has a map mode, where you can see where you are in the substation and save the position. As the user is in a computer, the data can be saved an uploaded to the cloud, and do an immediate comparison with past surveys.

Figure 20. Remote controlled drone

Figure 21. Remote controlled car

Advantages
- The user doesn't lose time, by walking around the substation.
- The robot can do a lot of things in the same time. Like filming, measuring and showing results in the same time.
- Surveys can be done in any kind of ground or weather condition.

Disadvantages
- If we use a drone the measure the PD, the possibility of cutting cables must be prevented.
- It is against the regulation to have something above the helmet.
- The user still need to be in the area, to control the robot.

Concept 5

Description:

Concept five is about adding components to the product when it is required, to form a modular product.

This concept is about making a modular product. The antenna was the only device that was already modular in the original product. A modular product can reduce the weight by remove the unused components. The product can be based on a smartphone, tablet, or even be made on its own. Than the user can add components, like a display, an antenna, a camera, or anything else when it is required. Then, for example, if the user wants to do a quick survey to one area of the substation, a huge battery may not be needed; or if the user is now an expert the display may not be needed. This concept would be suitable to adapt to many user-cases.

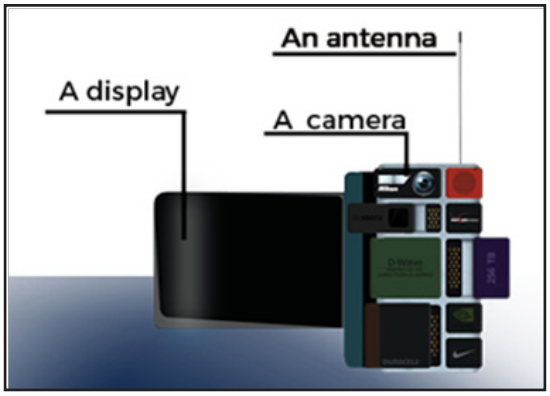

Figure 22. Modular smartphone

Advantages
· The user can choose the components that are required and make the product.
· The weight can be reduced by doing this.
· Experts can add a big display to see the details of the graphs.
· The product is more user-friendly and is adaptable to the user.
· If something is broken, it is easy to repair or replace it.
· Innovating the product though time is easier.

Disadvantages
· The user is required to know which components he will use.
· The components can't be too small because the user uses gloves.
· The components can be lost.

Concept 6
Description:
Concept six is about keeping the main idea of the original product, but just improve the way it's used and designed. The original product is a 'stand-alone' product, that works on its own. By improving the product on different levels, like the user-interface, the box, the design and so on, a new product can be created. Using a product that scans the PD and look like a normal scanner can be much more ergonomic for the user. A small display with graphs easier to understand can give more information.

Figure 23. Hand scanner

Advantages
· More user friendly and ergonomic.
· It is not that heavy anymore.
· Easier to work with and understand it.

Disadvantages
· The user still has to walk to every place and wait for the results.
· As everything is on the same place, it is not that light.

Concept 7
Description:
Concept seven is about having an automated system to look for PD, that way a user may not be needed all the time. This idea can be separated in two main parts: a car shaped vehicle and a ball-shaped drone. The idea is that there is an automated vehicle that does the work automatically. Once a month, it turns on and goes through the pre-established path, then it returns to a base. Its aim is collecting the data. Then, there is a base, that charges the vehicle, processes the data and via WIFI it sends a notification to an employee saying the state the substation is on and that the data has been uploaded to a cloud or sent to a computer.

The technology in that would be similar to the one in self-driving cars, they use different techniques to detect their surroundings. The most important part in this case would be the GPS, as an employee should program the path it has to follow through the substation. From there, you can include sensors, so that in every specific point it stops for a certain time to have more precise data, computer vision to avoid the possible obstacles and so on. The base has the processor, that receives the data via Bluetooth, it goes through the data and determines the state of the substation, it connects to the Wi-Fi and uploads the data to a database or sends it to a personal computer. While connected to the Wi-Fi it sends a message to employee in charge saying the state the substation is in and that the data has correctly been uploaded. It is also an inductive wireless charger.

The idea is that the drone's rotors are suspended inside a free moving spherical carbon fibre cage so they don't injure humans, or break when hitting obstacles. Its rotating camera stand - called a gimbal system - and HD camera are also housed in the protective cage. Images sent from the camera to a remote control unit, allow operators to see what the drone is seeing. Because all the delicate machinery is inside the cage, the drone can bounce between roof rafters and roll along uneven floors without damaging itself - or any nearby humans - and remain stable after a collision. Its structure also enables it to send back close-up images to operators. This technology could be used to collect and process the data in substations maintaining it in a low altitude level, but also to detect possible errors in metropolitan areas. There cannot be Wi-Fi everywhere it goes, so when it has connection the user can choose if upload it to a cloud immediately or wait until it returns.

Figure 24. Automated terrestrial vehicle

Advantages
- The user is not needed to go through the substation.
- Process is completely automated.
- The drone can be used for other user-cases, for example, it could also survey metropolitan areas in the underground.

Disadvantages
- It can be very expensive to develop.
- In the case of the car, there would have to be one in each substation, which could be very expensive for the consumer.
- In the case of the car, if the ground is too wet it can be problematic and not work properly.
- GPS may not work for all the substations.

Material type comparison
To determine what would be a suitable material, the different material types should be compared in the following:
- Stiffness
- Hardness
- Fracture toughness
- Operating temperature (Max/min)
- Price
- Density

Stiffness

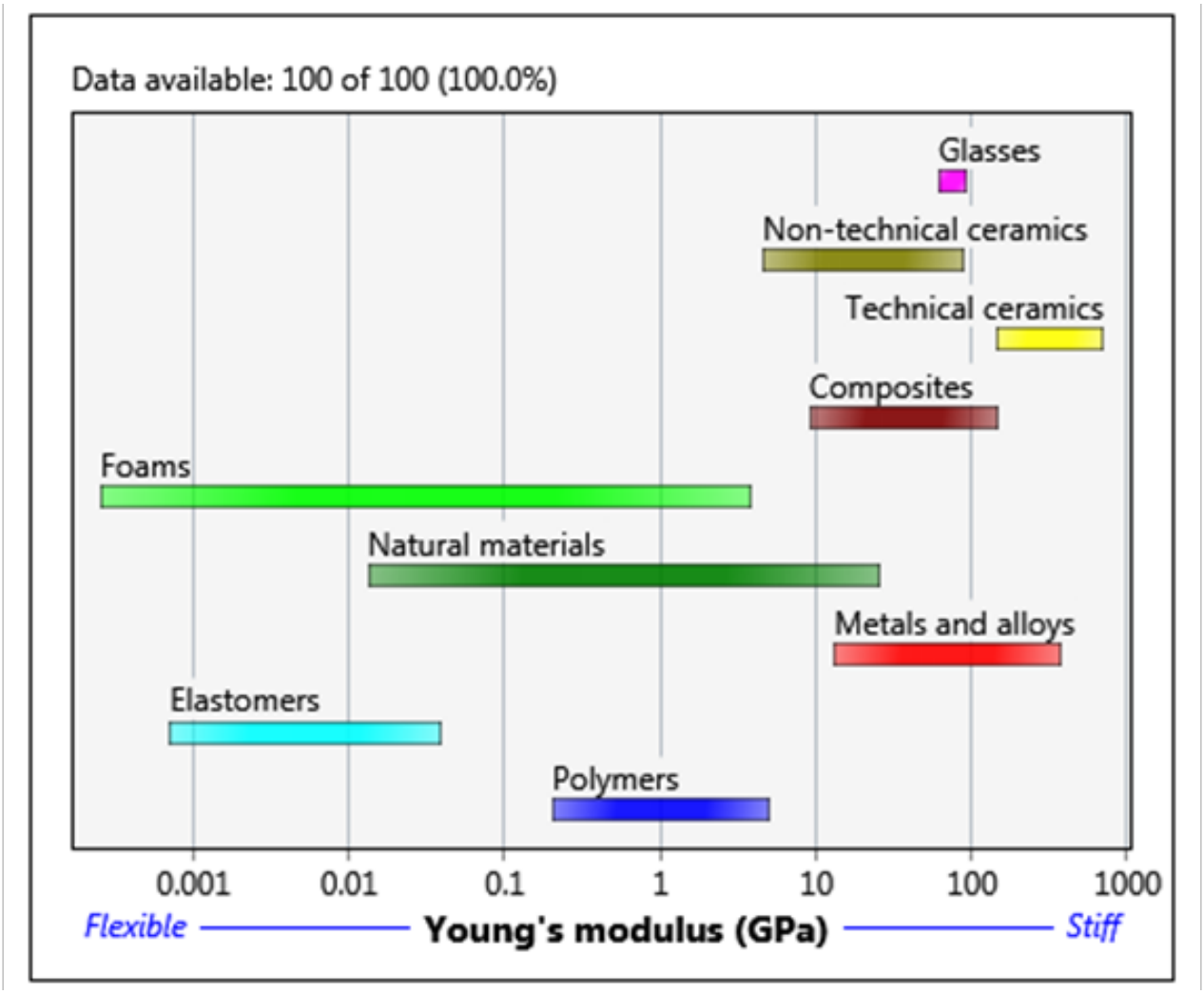

Figure 25. Young's modulus comparison (CES EduPack)

The stiffness of each material type is shown in the chart above. Ceramics have the highest stiffness, followed by composites and metals/alloys. Polymers, where ABS is located, has a moderate stiffness.

Hardness
Technical ceramics are the hardest material type, with composites and metals/alloys being towards the harder end of the chart. Polymers have a hardness rating that overlaps with both metals and composites and are similar to natural materials.

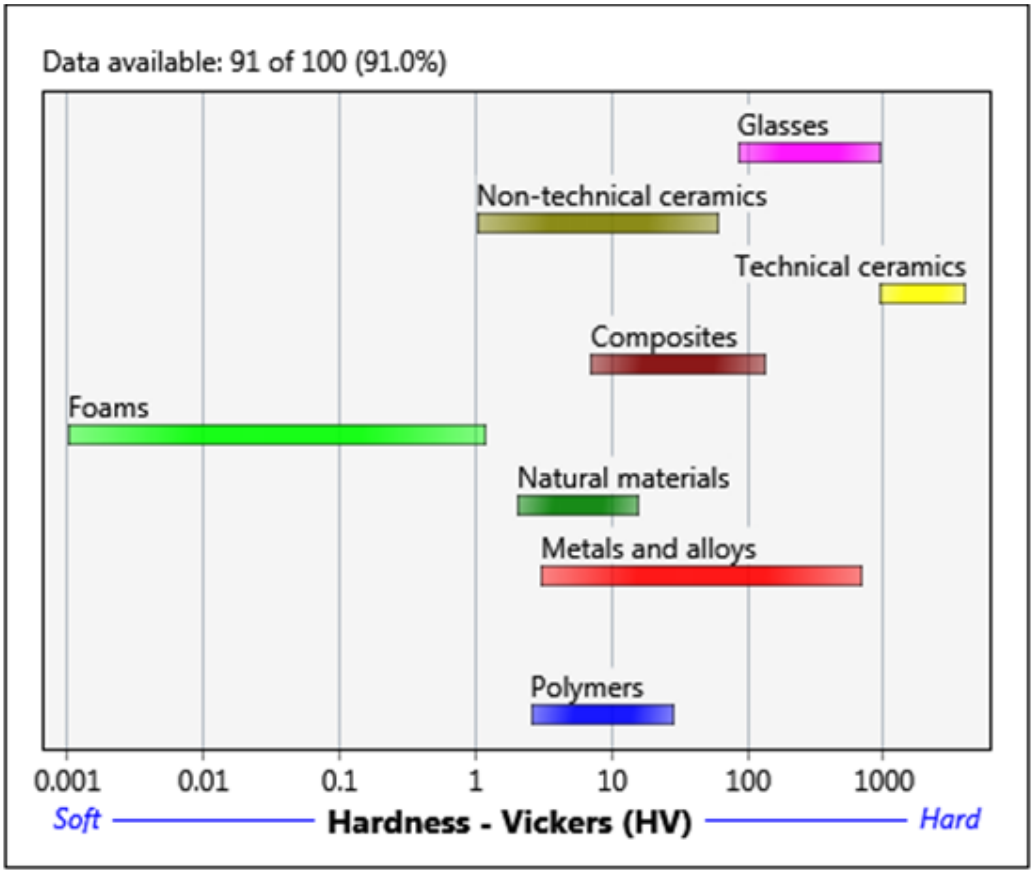

Figure 26. Hardness comparison (CES EduPack)

Fracture Toughness

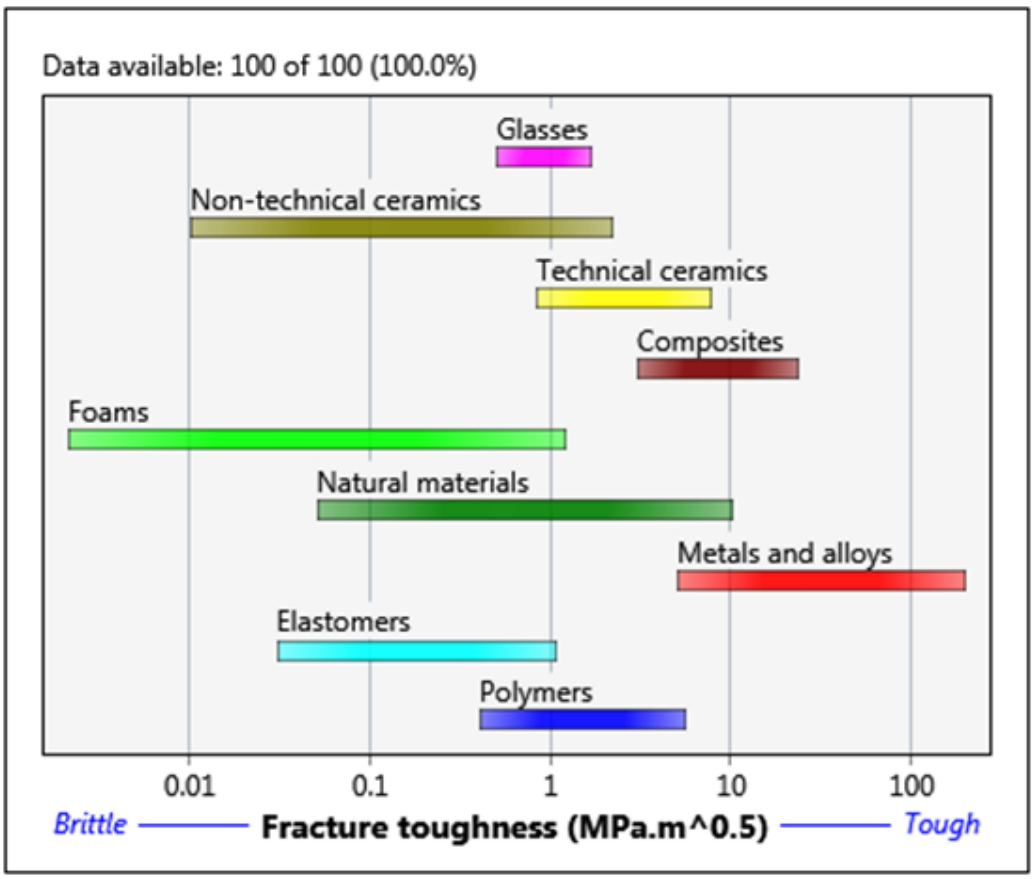

Figure 27. Fracture toughness comparison (CES Edupack)

Metals and Alloys have the highest resistance to fracturing. Composites also have a strong fracture toughness. Polymers and Ceramics have a similar fracture toughness to one another, with natural materials and non-technical ceramics having poor fracture toughness.

Maximum temperature

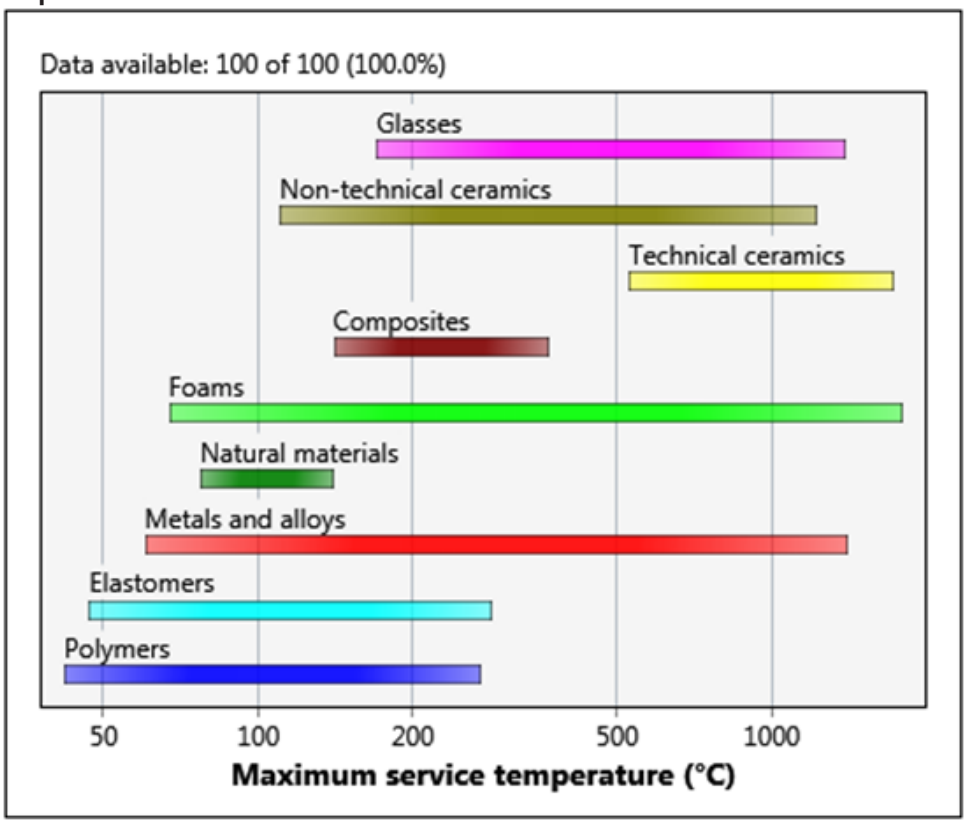

Figure 28. Maximum service temperature comparison (CES Edupack)

All material types exceed the maximum operating temperature required for the product, apart from certain polymers, elastomers and metals/alloys.

Minimum temperature

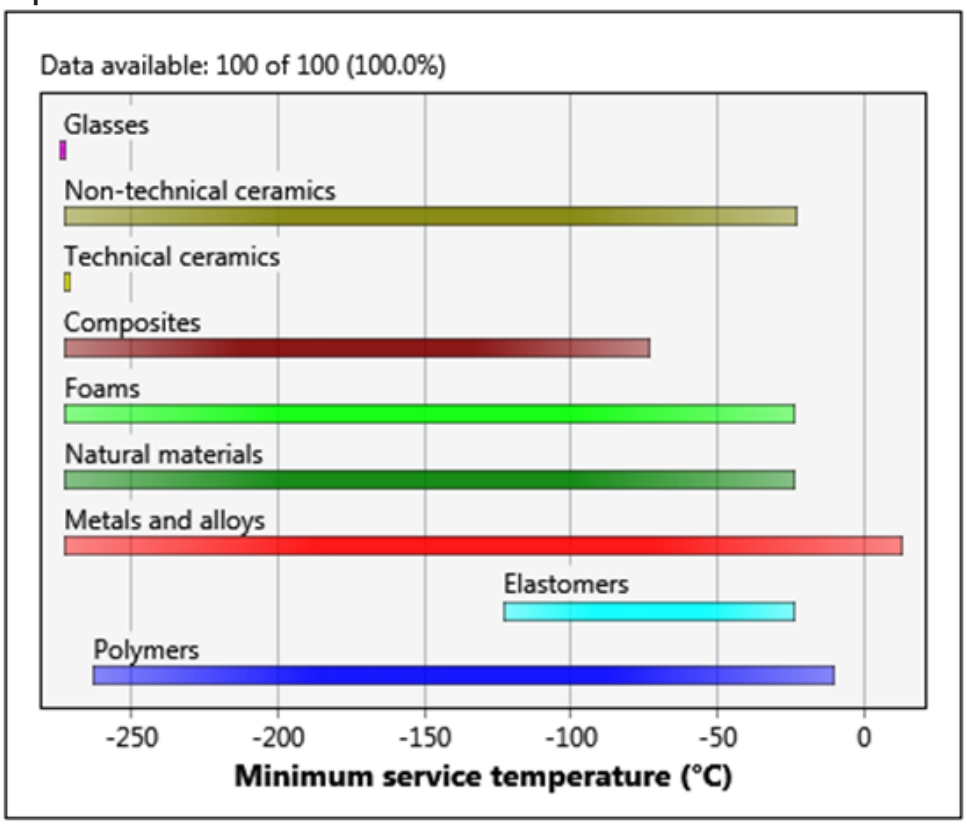

Figure 29. Minimum service temperature comparison (CES Edupack)

Apart from certain types of metals and polymers, all materials match or exceed the required minimum operating temperature of the product.

Price

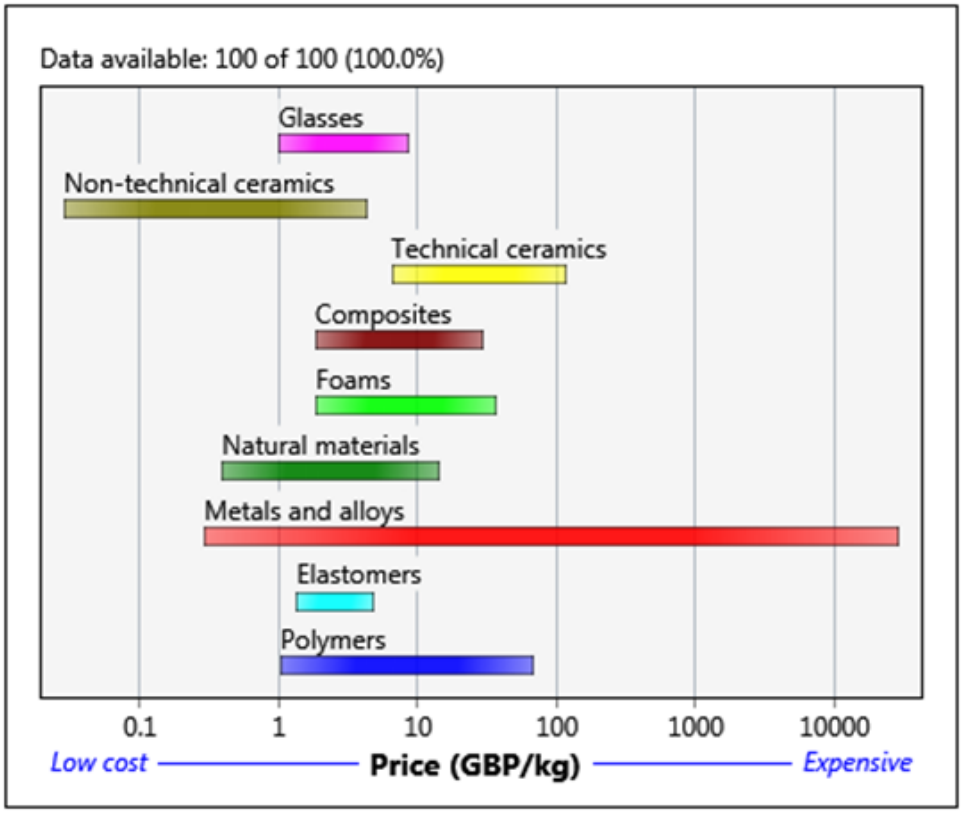

Figure 30. Price comparison (CES EduPack)

Price varies over time, unlike the mechanical properties of the materials, but the majority of materials are closely spaced together in between 1-100 £/kg, except the majority of metals/ alloys.

Density

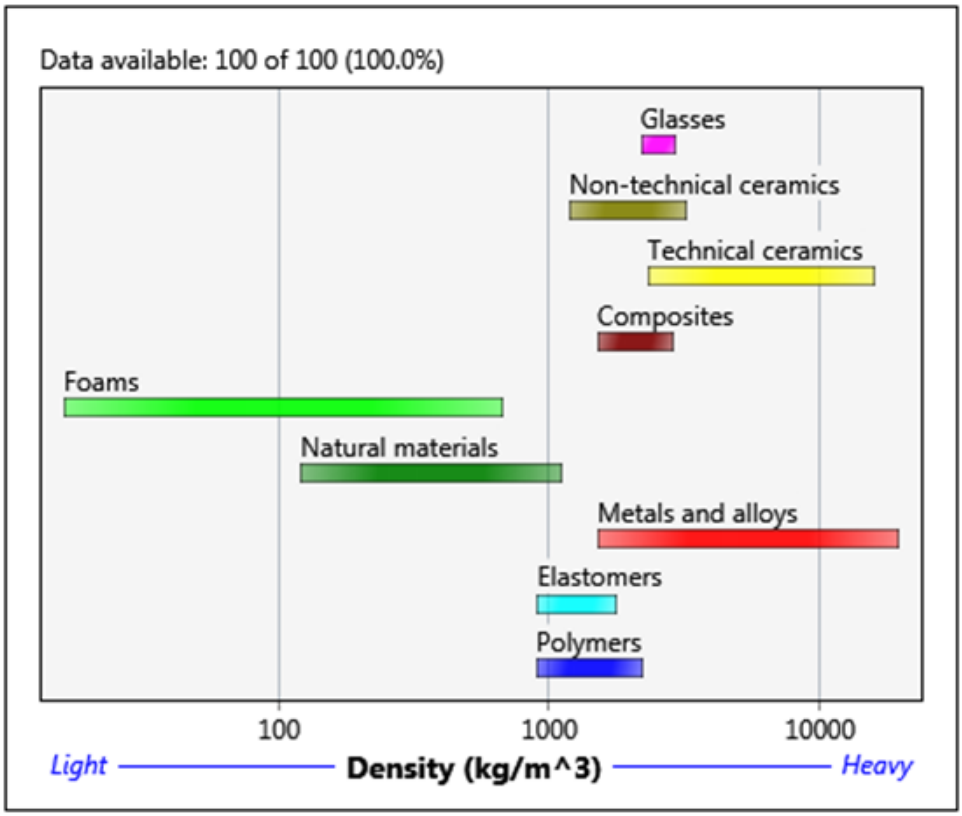

Figure 31. Density comparison (CES Edupack)

Foams and natural materials have the lightest density, with elastomers and polymers having a similar density of around 1000kg/m^3. Metals and ceramics are towards the heavier end of the chart.
Ideal material types can now be singled out by comparing the properties charts to the ideal properties.
- Foam- Not suitable due to low stiffness, fracture toughness and hardness
- Natural materials- average in all criteria but cannot be considered since it would not provide a good finish
- Elastomers- Not suitable since it has no hardness
- Ceramics- Good stiffness and hardness, but are not suitable due to being too brittle (low fracture toughness)
- Composites- Strong fracture toughness, hardness and stiffness. Average density. Would be suitable
- Metals/Alloys- High fracture toughness, hardness and stiffness, high density and price may be high- suitable
- Polymers- Suitable since it has suitable density and adequate hardness, fracture toughness and stiffness

Therefore, the material types that are most suitable would be:
- Polymers
- Metals/Alloys
- Composites

Further comparison of materials by type
Polymers
For polymers, only thermoset polymers have been selected due to their ability to be reused and recycled. Charts have been created which compare the properties of thermoset polymers but with a limit set for the exclusion of thermoset polymers below the minimum limit of the current ABS, since the material should aim to be an improvement.

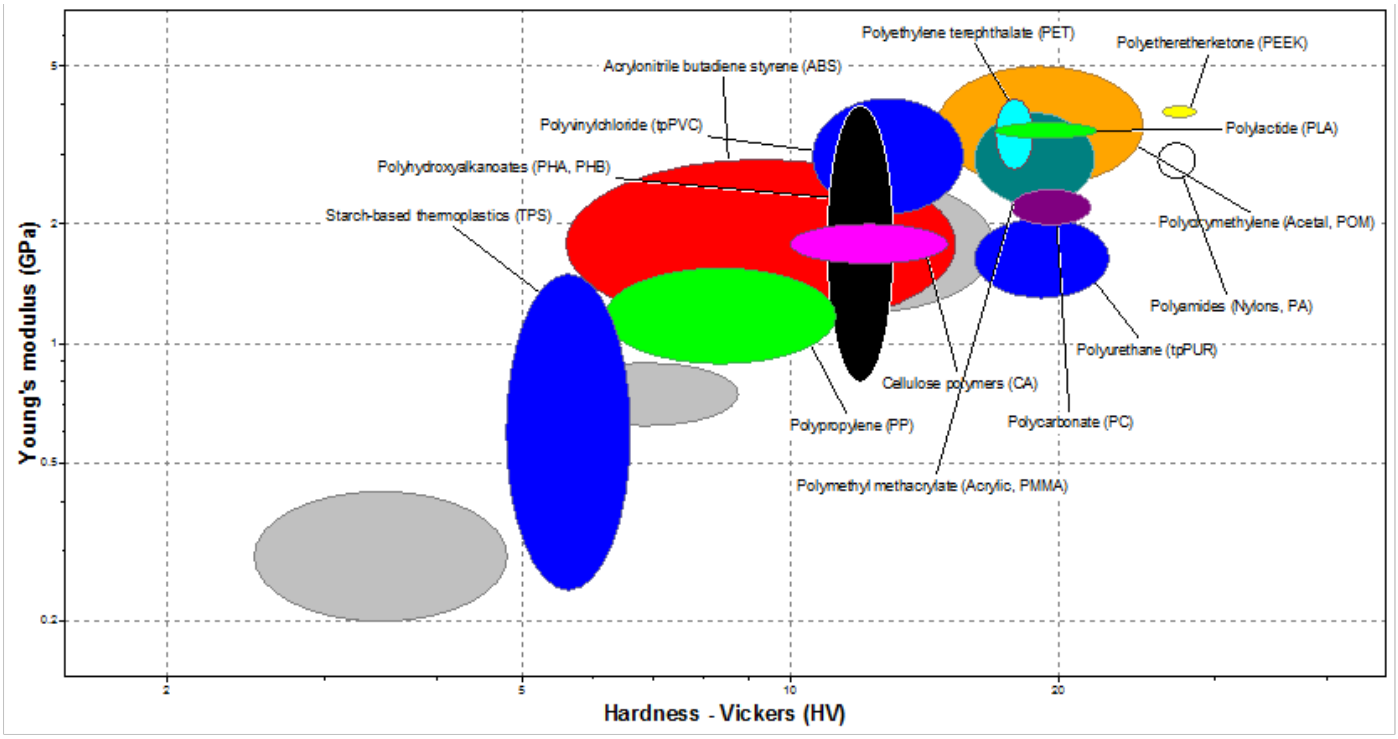

Figure 32. Polymer hardness comparison (CES Edupack)

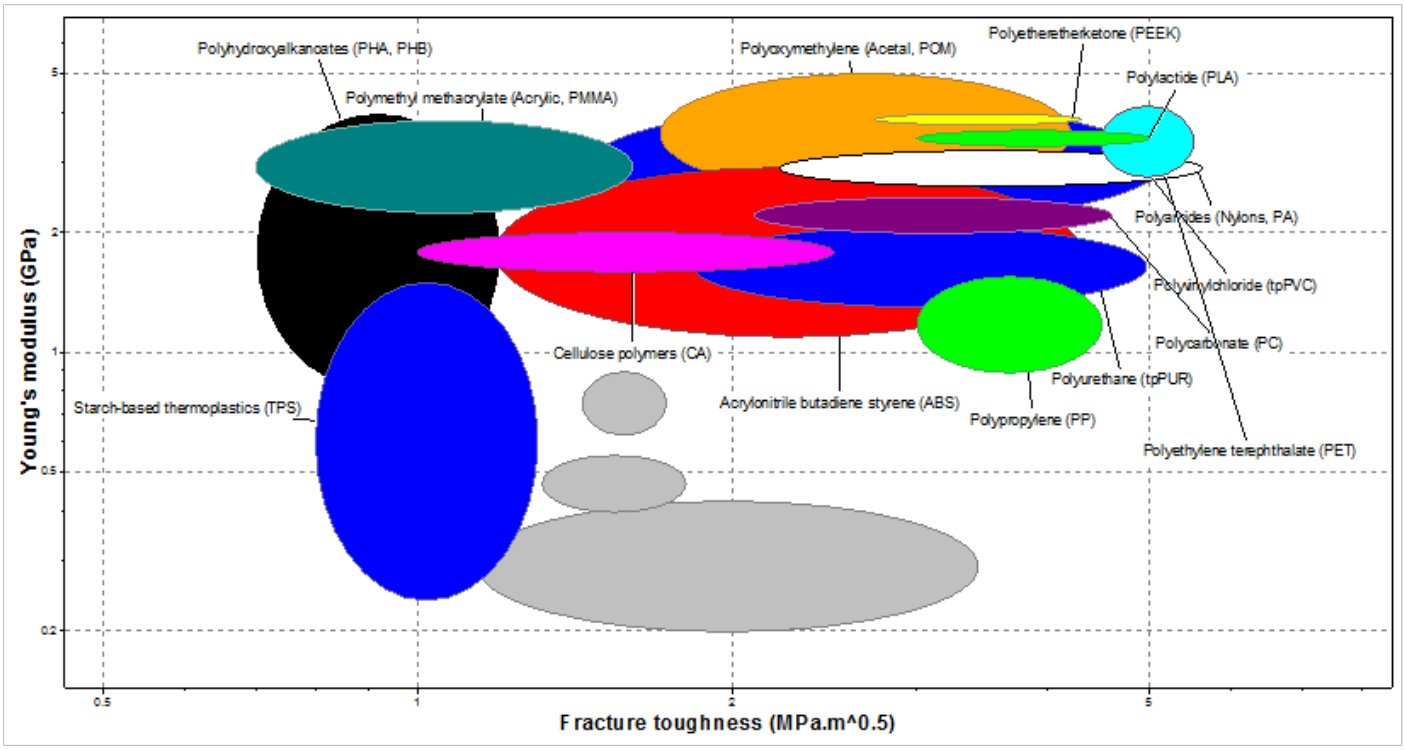

Figure 33. Polymer fracture toughness comparison (CES EduPack)

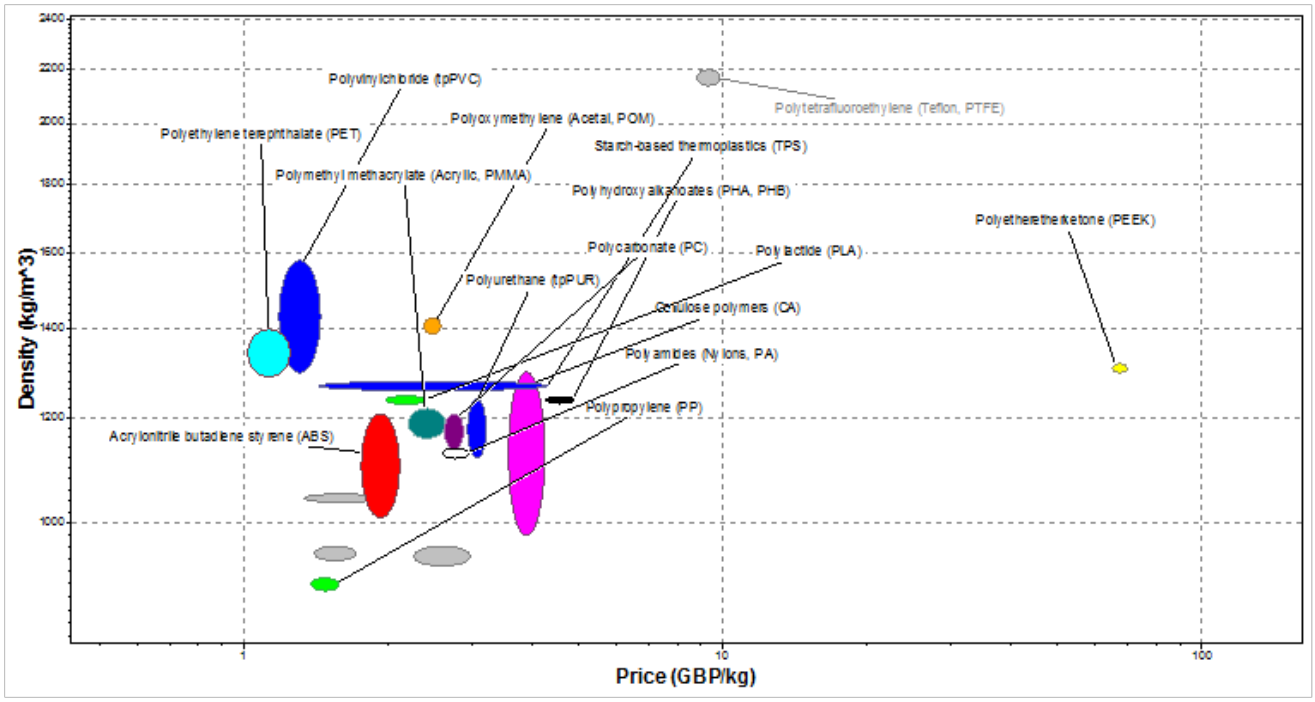

Figure 34. Polymer price comparison (CES EduPack)

From the comparison charts above, we can see that there are several ideal polymers that could be used for the product.

1. Polypropylene (PP). This has been selected since it has a high fracture toughness and hardness, with a slightly lower stiffness. Density is low, reducing mass.
2. Polycarbonate. Selected due to high fracture toughness, stiffness and hardness. More expensive than ABS or PP
3. ABS (Acrylonitrile Butadiene Styrene). Selected since it has suitable properties in terms of stiffness, hardness, price and density and is used in the current product.

Metals/Alloys

For the selection process, metals/alloys with properties below that of the minimum of the current material, ABS, have been excluded from the process. Comparison will be done with regards to stiffness, hardness, density, price and resistance to fracture.

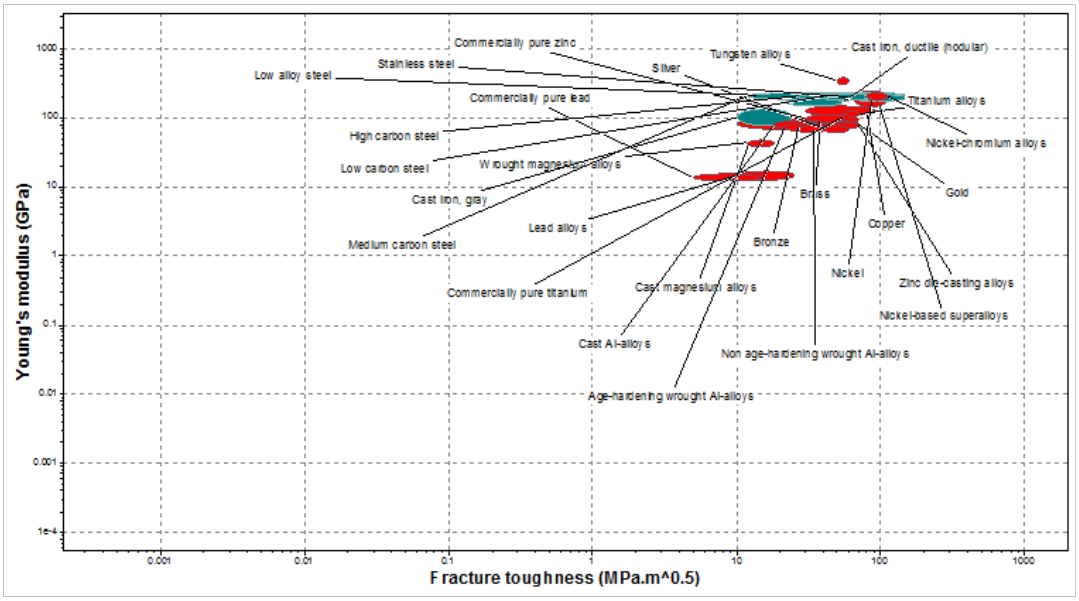

Figure 35. Metal fracture toughness comparison (CES EduPack)

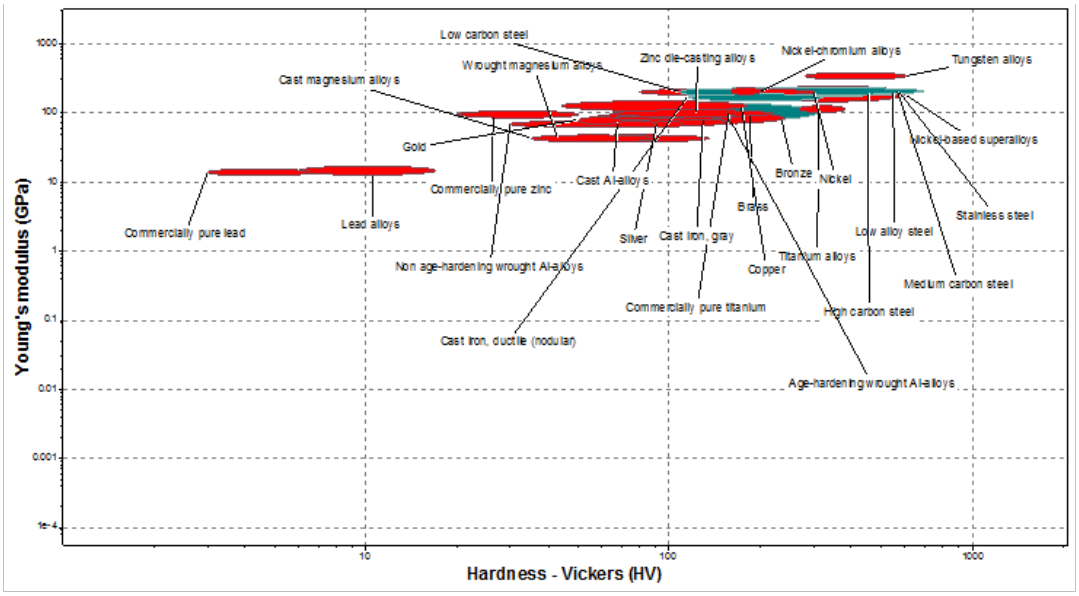

Figure 36. Metal hardness comparison (CES EduPack)

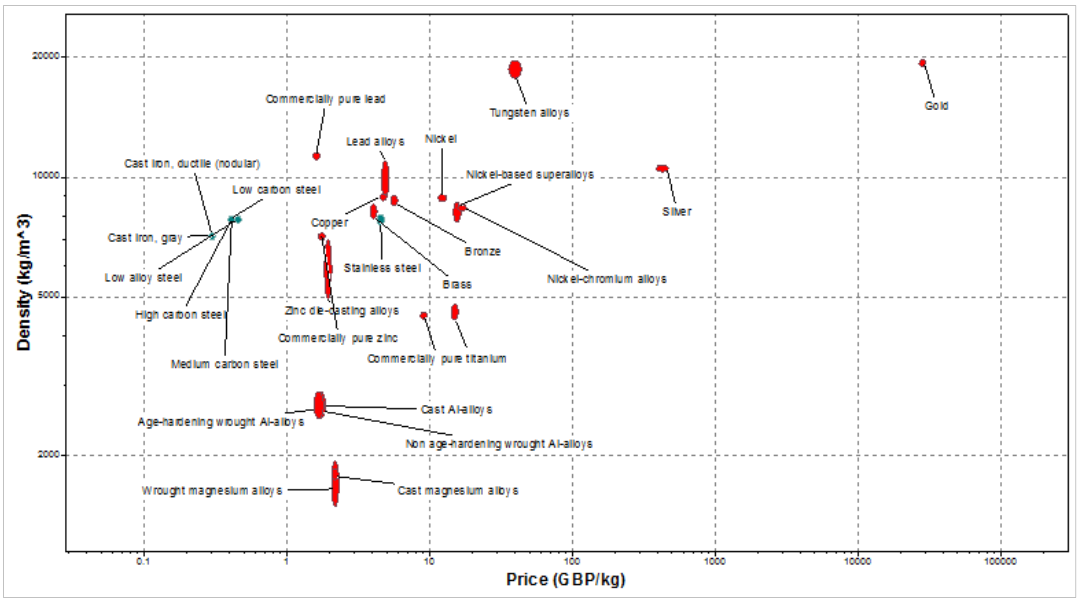

Figure 37. Metal price comparison (CES EduPack)

From the comparison charts above, we can see that there are several ideal metals that could be used for the product.

1. Cast Aluminium alloy. Inexpensive, medium density with good stiffness and fracture toughness
2. Wrought Aluminium alloys. Similar properties as cast Aluminium alloy, but different manufacturing process
3. Wrought magnesium alloys. Very low density, with good fracture toughness and stiffness.

Composites

Comparison of different composites will be done to find suitable composites that could be used for the product based on their properties.

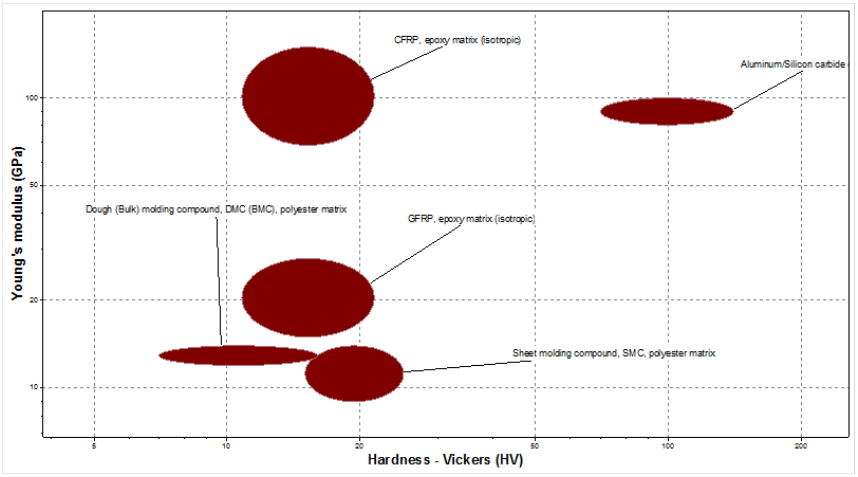

Figure 38. Composite hardness comparison (CES EduPack)

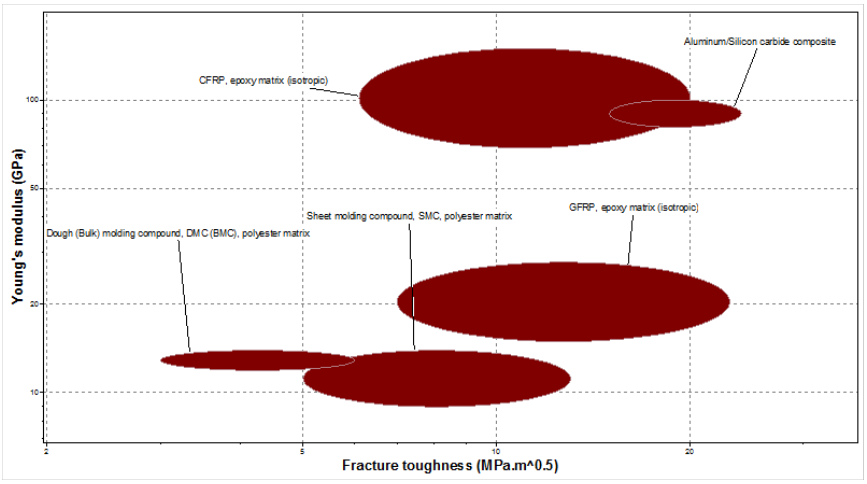

Figure 39. Composite fracture toughness comparison (CES EduPack)

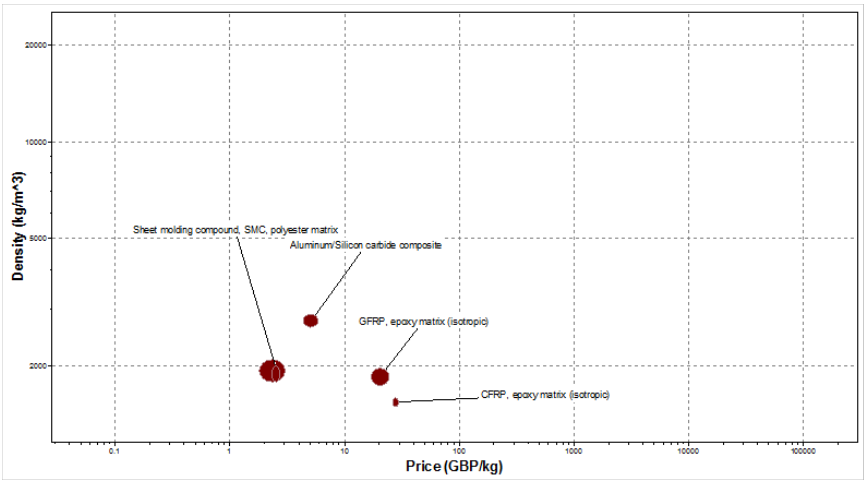

Figure 40. Composite price comparison (CES Edupack)

From the comparison charts above, we can see that there are composites that could be used for the product.
1. CFRP (Carbon Fibre Reinforced Plastic)- High price, high stiffness, low density and good fracture toughness
2. Aluminium/ Silicon carbide composite- Average pricing, high density compared to CFRP, high stiffness, hardness and resistance to fracturing

Direct comparison of ideal materials from a mechanical perspective
Direct comparison will give an insight into what materials are suitable for the task by comparing their mechanical properties.

Material	Price (€/kg)	Density (kg/m^3)	Young's modulus (GPa)	Fracture toughness (Mpa.m^0.5)	Hardness (HV)	Electrical Conductivity
Polypropylene	1.74	900	1.223	3.75	8.7	Good insulator
Polycarbonate	3.23	1175	2.22	3.35	19.7	Good insulator
ABS	2.28	1110	2	5.48	10.45	Good insulator
Cast Aluminium Alloy	2.04	2700	80.5	26.5	105	Good conductor
Wrought Aluminium Alloy (Age Hardened)	1.97	2700	74	28	110	Good conductor
Wrought Magnesium Alloy	2.58	1725	44.5	15	89	Good conductor
CFRP	32.80	1550	109.5	13.06	16.15	Poor conductor
Aluminium/ silicon carbide composite	6.02	2780	90.5	19.5	105	Good conductor

Table 1. Mechanical properties of shortlisted materials (CES EduPack)

Note: All values are an average of a given range from CES Edupack

From the comparison table, it can be seen that Polypropylene is not suitable, since it is inferior in every respect apart from price compared to ABS and is not biodegradable, despite being recyclable. The Aluminium alloys (cast and wrought), Magnesium alloy and the Aluminium/silicon carbide composite are strong electrical conductors and would present a safety hazard when used in a substation and would not be suitable, despite having suitable mechanical properties.
Both ABS and Polycarbonate can be injection moulded, but Polycarbonate can be difficult to injection mould and can warp if part thickness is not uniform, with sharp edges on the part not being acceptable. Both materials can be easily extruded, but this process is not suitable for manufacturing the tablet holder. In terms of finish, ABS produces a smooth high gloss, opaque finish that is aesthetically pleasing and Polycarbonate produces a smooth finish that can be clear if required. In terms of outdoor use, ABS is UV (Ultra-Violet) resistant, but requires the addition of stabilizers. Polycarbonate is also UV resistant.

Both materials are evenly matched, apart from increased difficulty using Polycarbonate in injection moulding. An ideal compromise could be a blend of ABS and PC, since this gives some advantages:

- Easier to process than PC
- Improved low temperature toughness than PC
- Improved room temperature toughness compared to ABS

There are very few disadvantages, with the only ones being poor resistance to hot water and a lower impact strength than PC. A direct comparison of this mixture's mechanical properties is shown below, along with ABS and Polycarbonate.

Material	Price (€/kg)	Density (kg/m^3)	Young's modulus (GPa)	Fracture toughness (Mpa.m^0.5)	Hardness (HV)	Electrical Conductivity
ABS/PC	3.39	1110	2.515	2.815	11.25	Good insulator
Polycarbonate (PC)	3.23	1175	2.22	3.35	19.7	Good insulator
ABS	2.28	1110	2	5.48	10.45	Good insulator

Table 2. Mechanical properties of final materials (CES Edupack)

The ABS/PC mixture is more expensive, but provides better stiffness and has good hardness. Impact resistance however, is lower than that of both ABS and Polycarbonate. Since the product will receive heavy use and may be accidentally dropped in use, ABS is the most suitable material for the body of the forearm unit.

Fabric selection

The fabric needs to meet the design requirements outlined in order to be successful. Cordura is a fabric that is focussed on durability and abrasion resistance. Developed by Invista, this fabric is commonly used around the world. There are many versions of Cordura with differing properties, but a suitable option would be Cordura TPX. Used for military as well as outdoor/travel purposes, TPX is a laminated fabric that is waterproof and retains the same wear and tear resistance as the normal Cordura fabric (Cordura.com, 2017).

Another possible option would be the use of normal Cordura otherwise known as a rip stop fabric, combined with a PU (Polyurethane) coating to give it waterproofing properties and retain the wear resistance of the fabric. This means it can come in a wide variety of colours and different knits and thread density. It is also a lightweight solution, with a 1000 denier Cordura fabric weighting 380gsm (grams per square metre) (Profabrics.co.uk, 2017). A 1.5x1m sheet of this fabric costs £10.63=€12.57 from a distributor (Profabrics.co.uk, 2017).

From this information, a suitable material would be a rip stop nylon fabric, such as Cordura, combined with a polyurethane coating to give it waterproof protection for the components. A regular rip stop fabric can also be used for the straps on the tablet unit, since it has suitable properties such as being wear resistant and available in a range of colours.

The straps would be adjusted using Velcro pads that would be stitched onto the rip stop nylon straps. Velcro is suitable for this application since it is simple and lightweight.

Appendix H – CONNECTION

Specifications

HARDWARE FEATURES	
Interface	USB 2.0
Antenna	Internal antenna
LED	Status
Weight	0.07 ounces / 2.1 grams (Without packaging)
Dimensions (W x D x H)	0.73x0.59x0.28in.(18.6x15x7.1mm)

WIRELESS FEATURES	
Wireless Standards	IEEE 802.11b, IEEE 802.11g, IEEE 802.11n
Frequency	2.400-2.4835GHz
Signal Rate	11b: Up to 11Mbps (dynamic) 11g: Up to 54Mbps (dynamic) 11n: Up to 150Mbps (dynamic)
Reception Sensitivity	130M: -68dBm@10% PER 108M: -68dBm@10% PER 54M: -68dBm@10% PER 11M: -85dBm@8% PER 6M: -88dBm@10% PER 1M: -90dBm@8% PER
Transmit Power	<20dBm
Wireless Modes	Ad-Hoc / Infrastructure mode
Wireless Security	Supports 64/128 WEP, WPA/WPA2, WPA-PSK/WPA2-PSK (TKIP/AES), supports IEEE 802.1X
Modulation Technology	DBPSK, DQPSK, CCK, OFDM, 16-QAM, 64-QAM

OTHERS	
Certification	CE, FCC, IC, RoHS
Package Contents	150Mbps wireless N Nano USB adapter TL-WN725N Resource CD Quick Installation Guide
System Requirements	Windows 8.1/8(32/64bits), Windows 7(32/64bits), Windows Vista(32/64bits), Windows XP(32/64bits), Mac OS X 10.7~10.10, Linux
Environment	Operating Temperature: 0℃~40℃ (32℉~104℉) Storage Temperature: -40℃~70℃ (-40℉~158℉) Operating Humidity: 10%~90% non-condensing Storage Humidity: 5%~90% non-condensing

GNSS Receivers	R2 GNSS receiver	Pro 6H receiver	Pro 6T receiver	R1 GNSS receiver
				
DGNSS accuracy postprocessed*	>1 cm	10 cm	50 cm	50 cm
DGNSS accuracy real-time*	>1 cm	10 cm	<1 m	<1 m
H-Star technology-capable	No	Yes	No	No
GLONASS-capable	Yes	Yes	Yes (Optional via Floodlight)	Yes
EVEREST multipath rejection	Yes	Yes	Yes	Yes
Integrated GNSS receiver and antenna	Yes	Yes	Yes	Yes
RTX compatible	Yes	No	No	Yes (Trimble ViewPoint RTX™)
Integrated SBAS	Yes	Yes	Yes	Yes
Integrated OmniSTAR	Yes (VBS, XP, HP, or G2)	No	No	No
NMEA output	Yes (Optional)	Yes (Optional)	Yes (Optional)	Yes (Non-RTX)
RTCM input	Yes	Yes	Yes	Yes
Integrated Bluetooth	Yes	Yes	Yes	Yes
Weight	1.08 kg / 2.38 lbs	1.04 kg / 2.3 lbs	1.04 kg / 2.3 lbs	0.187 kg / 0.4 lbs
Battery life	5 hours (varies with temperature)	>12 hours	>12 hours	> 10 hours
Ruggedness	Withstands 2 m (6.6 ft) drop onto concrete	Withstands 1.2 m (4 ft) drop to plywood over concrete	Withstands 1.2 m (4 ft) drop to plywood over concrete	Withstands 1.2 m (4 ft) drop to plywood over concrete
Environmental	IP65	IP65	IP65	IP65
Operating temperature	–20° C to 55° C / –4° F to 131° F	–20° C to 60° C / –4° F to 140° F	–20° C to 60° C / –4° F to 140° F	–20° C to 60° C / –4° F to 140° F

DATASHEET

Trimble R1

GNSS RECEIVER

MAKE ACCURACY PERSONAL

The Trimble® R1 is a rugged, compact, lightweight GNSS receiver that provides professional-grade positioning information to any connected mobile device using Bluetooth® connectivity. Purpose-built for mapping and GIS professionals in a variety of organizations, including environmental agencies, government departments, and utility companies, the standalone Trimble R1 receiver enables you to collect higher-accuracy location data with the device you already use—whether it is a modern smart device, such as a mobile phone or tablet, or traditional integrated data collection handheld or tablet.

Improved GNSS Positioning— On Any Device

For users challenged with collecting high-accuracy location data using their existing consumer-grade devices, the Trimble R1 receiver is the solution. No matter what smart device you choose—from iOS to Android—for collecting GIS data, inspecting, or managing assets, the Trimble R1 lets you achieve a greater level of reliable spatial accuracy than your current smart phone or tablet is able to provide on its own.

Because the Trimble R1 is compatible with a variety of devices, your current technology investments are maximized, all while ensuring you collect reliable higher accuracy data. In addition, the investment made in your Trimble R1 GNSS receiver allows you to upgrade to the latest smart device or share the R1 between multiple devices whenever needed, saving you money and keeping you productive and efficient.

Professional Data Collection in More Places

Capable of supporting multiple satellite constellations, including GPS, GLONASS, Galileo and BeiDou, the Trimble R1 provides a truly global solution. Delivering GNSS positions in real-time without the need for postprocessing, correction sources such as SBAS, VRS, or RTX networks can be applied to suit your location and desired accuracy—giving you confidence in achieving reliable GNSS information anywhere in the world.

Obtain submeter accuracy by using the Trimble R1 with the optional Trimble ViewPoint RTX service. Trimble ViewPoint RTX service* offered with the Trimble R1 provides internet-delivered submeter accuracy wherever cellular communications are available or over satellite L-band, even in remote locations.

Support Your Daily GIS Workflows

The Trimble R1 integrates with the flexible and robust workflows of Trimble Mapping & GIS software—including Trimble TerraFlex™, Trimble TerraSync™, and Trimble Positions™ software—or third-party applications. No matter what mobile device you use, Trimble's professional data collection software means you can be certain your GIS is populated with quality data you can trust.

Built to Work the Way You Do

Weighing just 187 g and measuring at 11.2 cm x 6.8 cm x 2.6 cm, the Trimble R1 can go wherever you go. Easily carry around the Trimble R1 as you perform all of your data collection and asset management tasks. The receiver can be polemounted, carried in a vest pocket, or attached to a belt using the optional belt pouch—giving you the flexibility to choose how you use it while keeping you streamlined and cable-free, thanks to wireless Bluetooth connectivity. Plus the all-day battery life means it will keep going as long as you do. Built to last with certified MIL-STD-810 ruggedness and IP65 rating, the Trimble R1 receiver won't quit when the going gets tough.

Flexible and practical, accurate and rugged—the innovative Trimble R1 GNSS receiver delivers professional-level positions to everyone.

Key Features

- Small, rugged, lightweight GNSS receiver for great mobility
- Flexibility to choose your data collection device
- Bluetooth connection to Trimble handhelds or consumer-grade smart devices
- Provides higher-accuracy location data
- Flexible, professional data collection in more places

*RTX available through Trimble applications

DATASHEET

Trimble R1 GNSS RECEIVER

GNSS

Sensor type	L1/G1 GNSS receiver and antenna
Systems	GPS, GLONASS, Galileo, Beidou, QZSS
Channels	44-channel, parallel tracking
Correction sources	SBAS, ViewPoint RTX, QZSS, VRS
SBAS	4-channel, parallel tracking WAAS, EGNOS, MSAS, GAGAN, SBAS ranging
Receiver protocols	NMEA 0183 v4.00, Binary
Update rate	1 Hz
Time to first fix	45s typically
Reacquisition	< 2s
Real time correction protocols	CMR, CMR+, CMRx RTCM 2.1, 2.2, 2.3, 3.0, 3.1
SBAS accuracy[1]	< 100 cm
ViewPoint RTX[1]	50 cm HRMS
Code DGNSS accuracy (real-time)[1]	75 cm + 1 ppm HRMS
Maximum speed	1,850 kph / 1,150 mph / 999 knots
Maximum altitude	9,000 m (29,520 ft)

INTERFACES

Port	Bluetooth 2.1 + EDR, USB 2.0 (charge/firmware update)
Bluetooth transmission	Class 2 (10 m) iAP2 and 2.1 EDR
Bluetooth frequency	2.400 - 2.485 GHz
Raw measurement data	Trimble GSOF, Binary
Communication status LED	Bluetooth status, GNSS, corrected GNSS
Power status LED	Charging, charging (full), 3 stage battery status (> 50%, 15 – 50%, < 15%)

BATTERY AND POWER

Battery type	Integrated Lithium-Ion
Battery capacity	3.7v 15Wh
Battery life	10+ hours
Charging time	5 hours (typical, with supplied charger)
External antenna voltage output	3 VDC
External antenna input impedance	50 Ohms

ENVIRONMENTAL

Water/Dust Ingress	IP65
Temperature (MIL-STD-810G)	
Operation	–20 °C to +60 °C (–4 °F to +140 °F)
Storage	–30 °C to +70 °C (–22 °F to +158 °F)
Drop shock (non-operating)	MIL-STD-810G Method 516.5 Procedure IV 1.2 m (4 ft) to plywood over concrete
Vibration	MIL-STD-810G Method 514.5 Procedure I Category 24
Relative humidity	MIL-STD-810G Method 507.6 95% non-condensing
Altitude rating	MIL-STD-810G Method 500.5
Maximum storage altitude	12,192 m (40,000 ft)
Maximum operational altitude	9,000 m (29,520 ft)

MECHANICAL

Enclosure dimensions	11.2 x 6.8 x 2.6 cm (4.4 x 2.7 x 1.0 in.)
Weight	187 g (0.4 lb)
Power connector	Micro-B USB female
External antenna connector	SMB female

INTERNAL ANTENNA

Frequency range	GPS L1 and GLONASS L1

SUPPORTED PLATFORMS

iOS (7x or greater), Android (4.1 or greater), Windows (7 or greater), WEHH (6.5x)

COMPLIANCE

FCC Part 15 (Class B device), CE Mark, RoHS

IN THE BOX

- Trimble R1 GNSS receiver
- AC Power adaptor/charger
- USB data cable
- Belt pouch/clip
- Documentation

SOFTWARE COMPATIBILITY

Please refer to the Product Compatibility list.
(www.trimble.com/mappingGIS/productcompatibility)

Specifications subject to change without notice.

"Made for iPhone" and "Made for iPad" mean that an electronic accessory has been designed to connect specifically to iPhone or iPad respectively, and has been certified by the developer to meet Apple performance standards. Apple is not responsible for the operation of this device or its compliance with safety and regulatory standards. Please note that the use of this accessory with iPhone or iPad may affect wireless performance. iPad, iPhone and Retina are trademarks of Apple Inc., registered in the U.S. and other countries. iPad mini is a trademark of Apple Inc.

1 Accuracy and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. Always follow recommended GNSS data collection practices. Specified ViewPoint RTX accuracy is typically achieved within 10 minutes and accuracy levels range from submeter to 50 cm depending on conditions.

Contact your local Trimble Authorized Distribution Partner for more information

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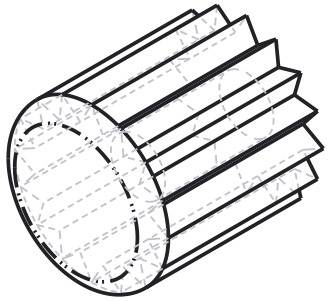
Westminster CO 80021
USA

EUROPE
Trimble Germany GmbH
Am Prime Parc 11
65479 Raunheim
GERMANY

ASIA-PACIFIC
Trimble Navigation
Singapore Pty Limited
80 Marine Parade Road
#22-06, Parkway Parade
Singapore 449269
SINGAPORE



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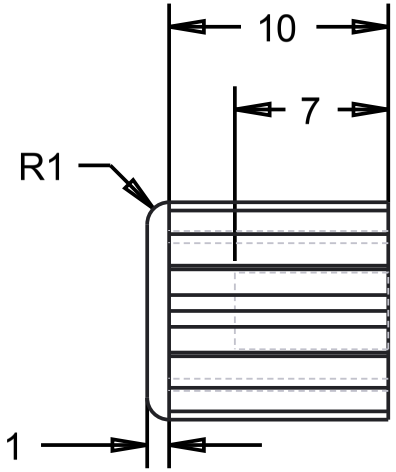

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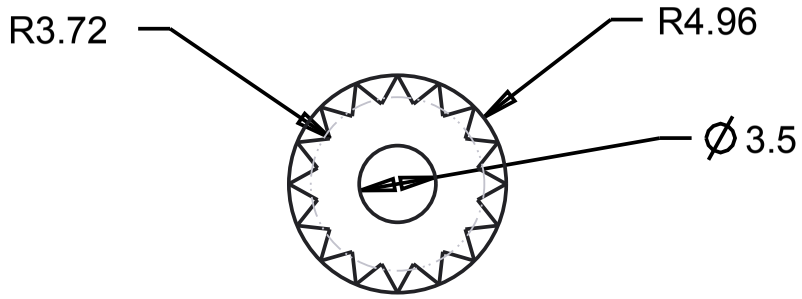
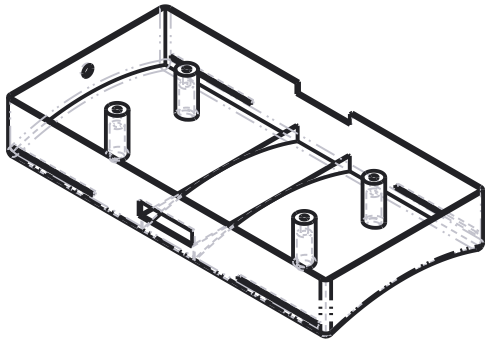


ELEVATION

THIRD ANGLE PROJECTION	ADJUSTMENT SCREW
	VOLUME:579.498 MM^3
SCALE 3:1	UNITS: MM



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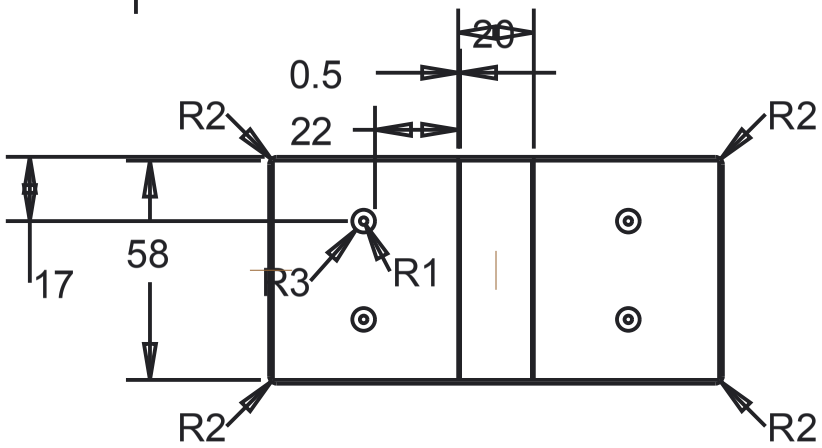
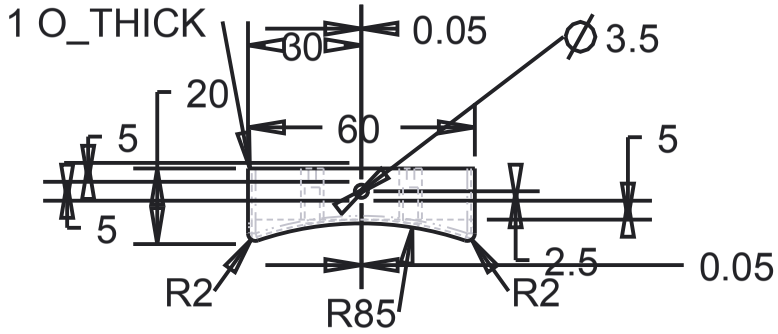


PLAN



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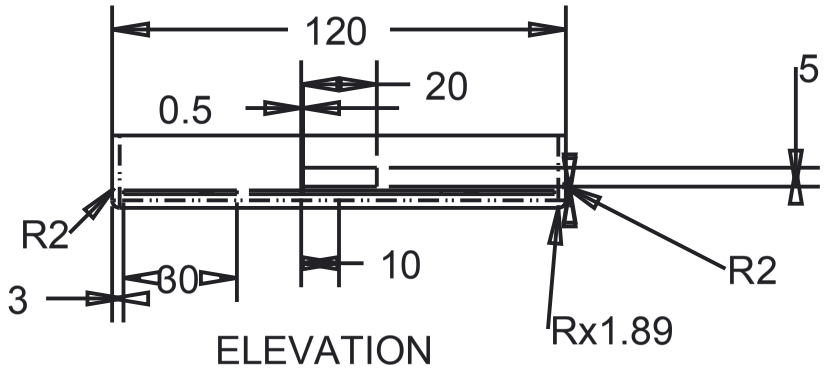
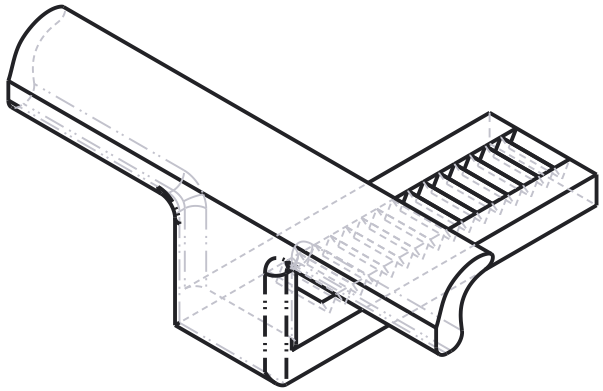


ELEVATION

THIRD ANGLE PROJECTION	BOTTOM CASING
	VOLUME:13852.7 MM^3
SCALE 1:2	UNITS:MM



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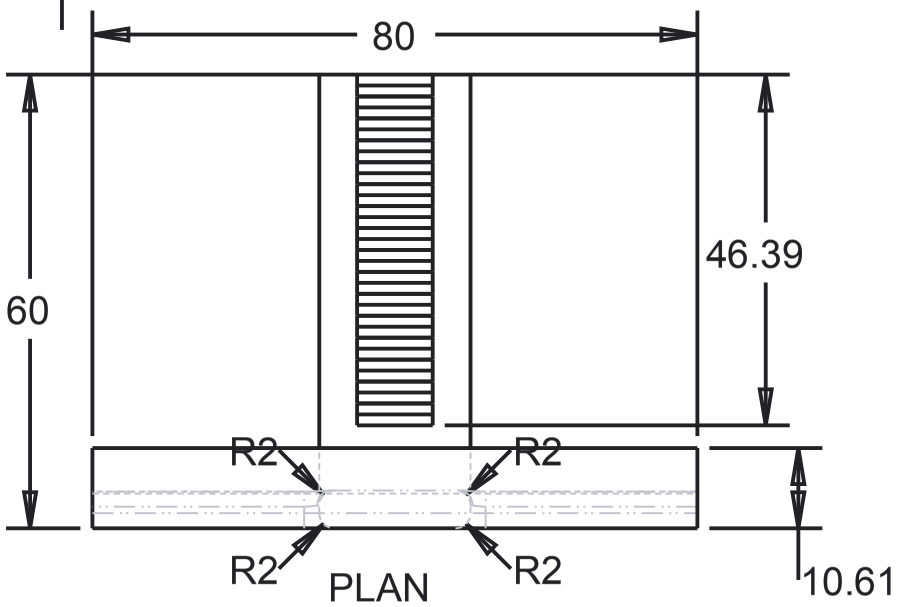

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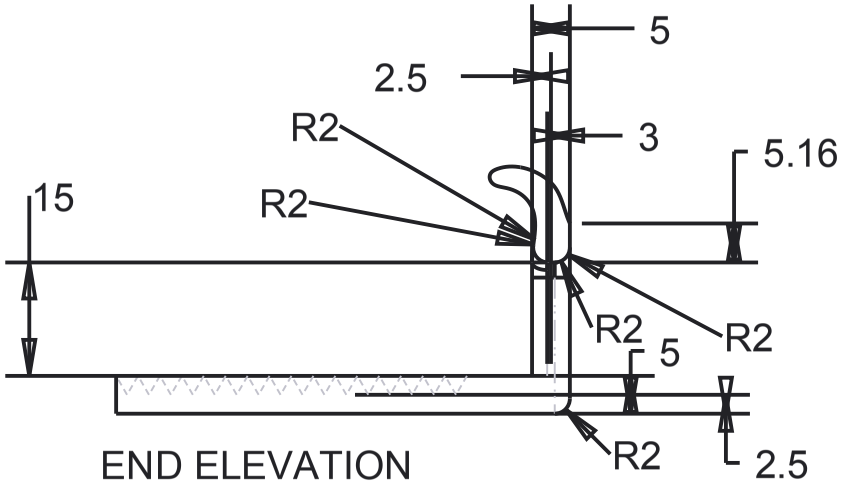

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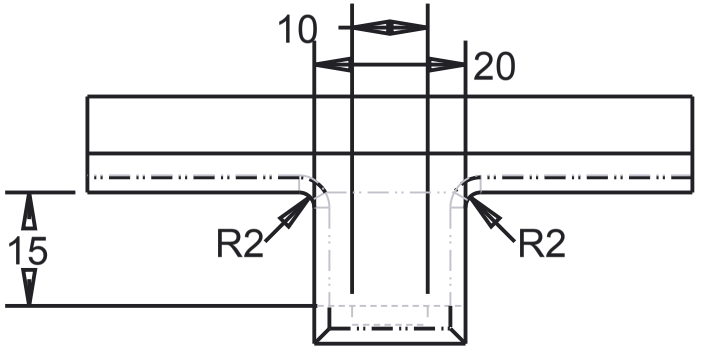
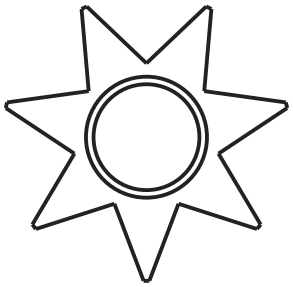
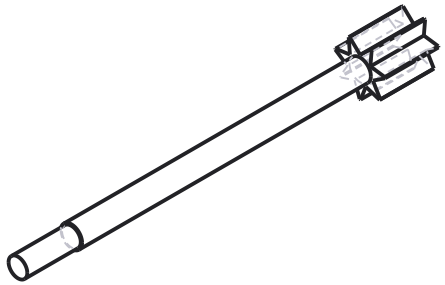


ELEVATION

THIRD ANGLE PROJECTION	BOTTOM CLAMP
	VOLUME:11908.8 MM^3
SCALE 1:1	UNITS:MM



DETAIL A
SCALE 4.000



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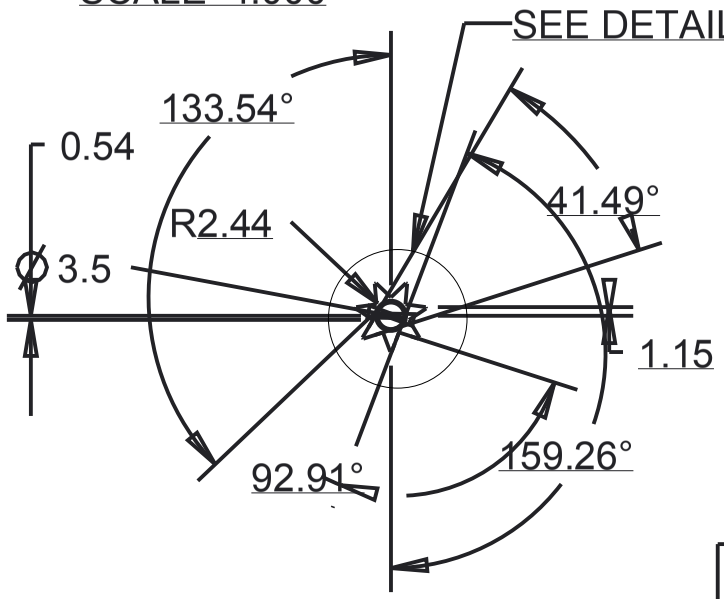

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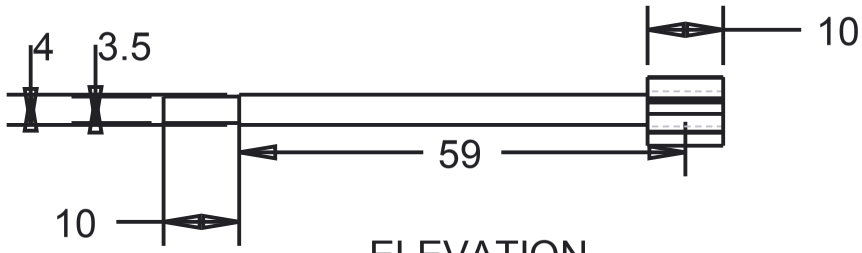
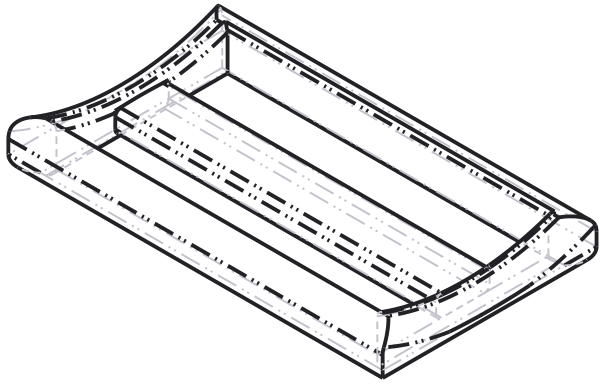


ELEVATION

THIRD ANGLE PROJECTION	GEAR AND AXLE
	VOLUME:1144.13 MM^3
SCALE 1:1	UNITS:MM



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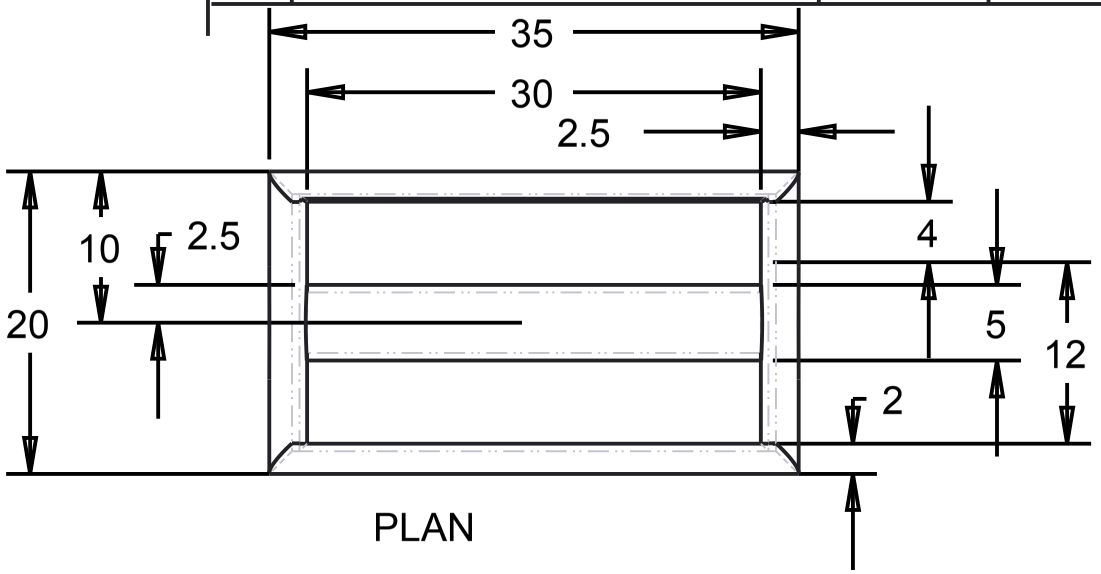

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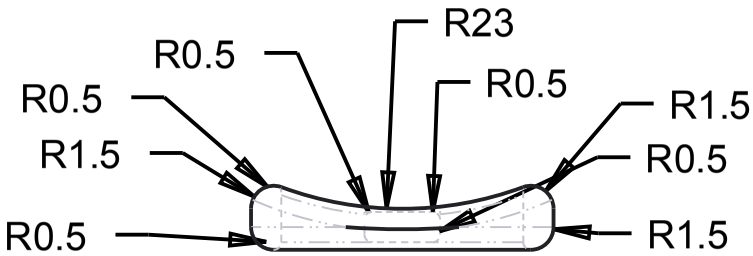

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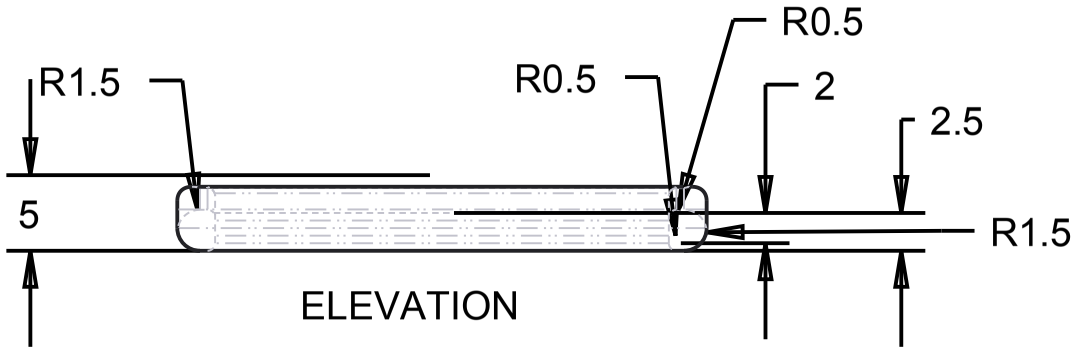
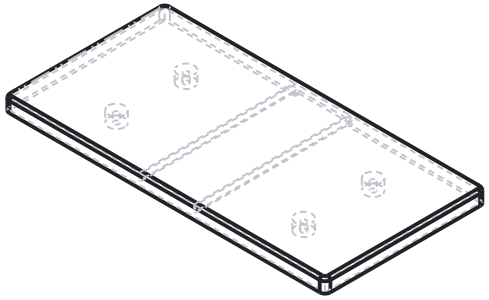


ELEVATION

THIRD ANGLE PROJECTION	STRAP BUCKLE
	VOLUME:1029.73 MM^3
SCALE 2:1	UNITS:MM



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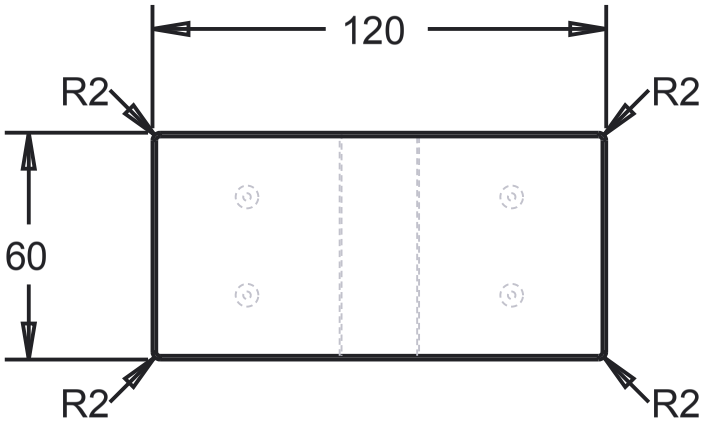

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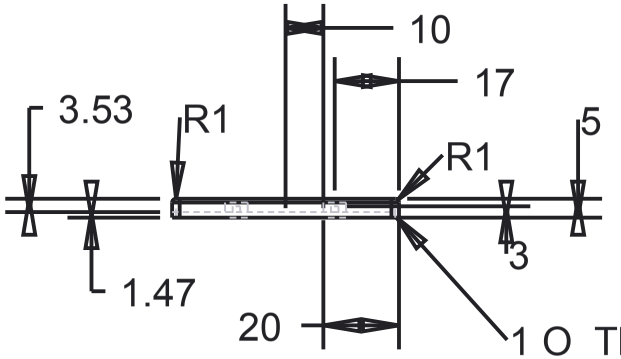

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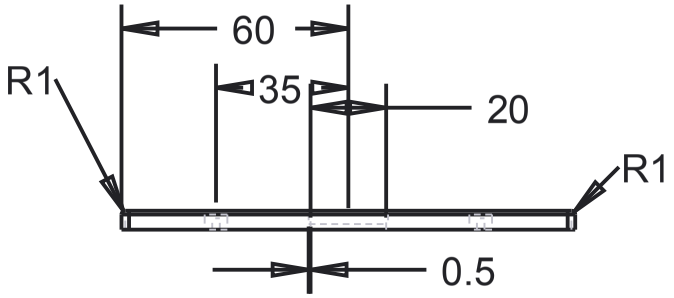
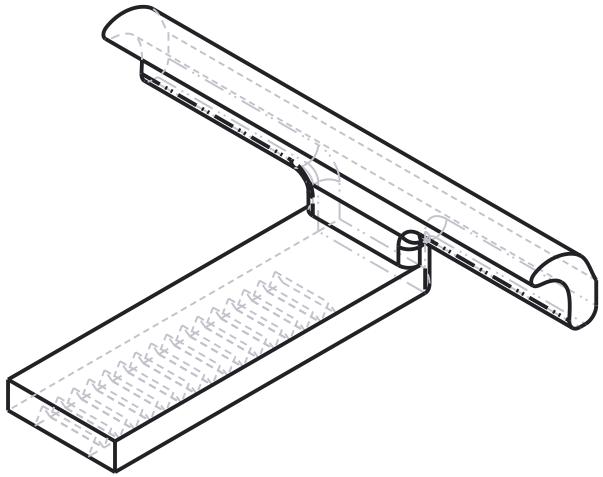


ELEVATION

THIRD ANGLE PROJECTION	TOP CASING
	VOLUME:9062.64 MM^3
SCALE 1:2	UNITS: MM



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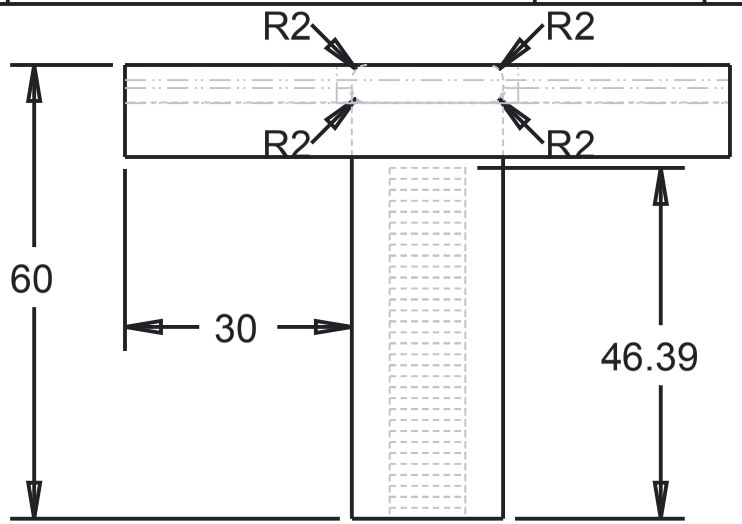

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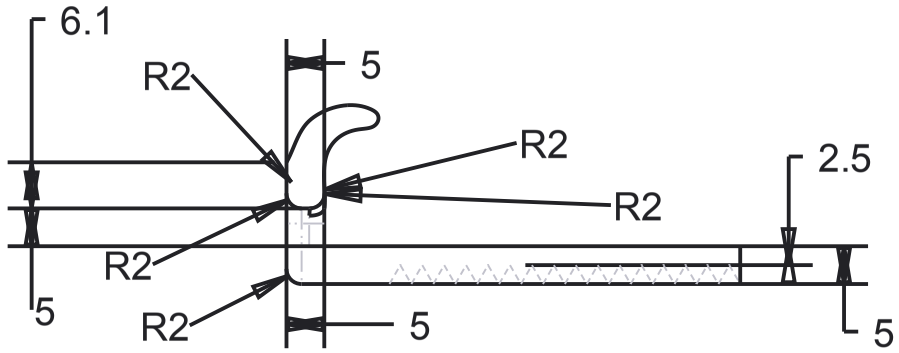
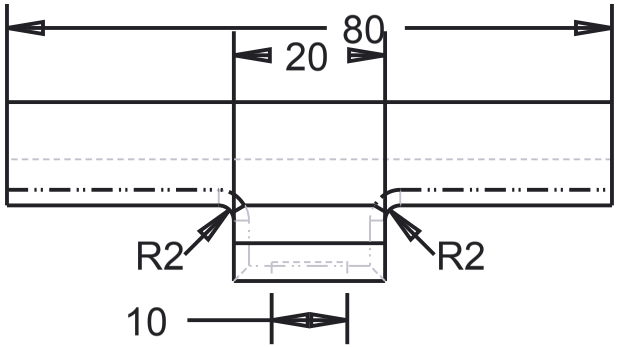


END ELEVATION



ELEVATION

THIRD ANGLE PROJECTION	TOP CLAMP
	VOLUME:1190.7 MM^3
SCALE 1:1	UNITS:MM

Getac

Rugged Mobile Computing Solutions

Z710

Fully Rugged 7" Android Tablet

- 7" LumiBond® Display with Getac Sunlight Readable Technology and Glove-enabled Capacitive Touchscreen
- 6 Feet Drop and IP65 Certified
- Optional 1D/2D Imager Barcode Reader and RFID
- Optional 3.5G WWAN for data and voice communication
- SiRFstarIV™ High Sensitivity GPS

ATEX | CERTIFIED MIL-STD 810G | INGRESS PROTECTION IP65 | 1,8m DROP TEST | ANSI CERTIFIED PRODUCT

Office Dock

Vehicle Dock

Z710 Fully Rugged 7" Android Tablet

Specifications

Operating System	Android 4.1
Mobile Computing Platform	OMAP 4430 Dual Core 1 GHz
Display	7.0" IPS TFT LCD WSVGA (1024 x 600); LumiBond® display with Getac sunlight readable technology Capacitive touchscreen with glove on
Storage & Memory	1GB MDDR 16GB NAND flash
Expansion Slots	Micro SDHC (up to 32GB)
Alphanumeric Data Entry	Soft input panel (SIP) on screen keyboard
I/O Interface	USB (client 2.0) x 1 USB (Host 2.0) x 1 Microphone x 1 Speaker x 1 DC in Jack x 1 Docking connector (30-pin) x 1
Communication Interface	Optional 3.5G WWAN (HSPA+/UMTS/EDGE/GPRS/GSM) for data and voice communication 802.11 b/g/n Bluetooth (v2.1+EDR class 2) SiRFstarIV™ GPS (with internal antenna) RF antenna pass-through for GPS and WWAN
Software	File Manager GPS-ECompass Barcode Utility[i] Barcode Config[i] RFID Reader Utility[i] Google Mobile Service (Calendar, Clock, Gallery, QuickSearchBox, Google Play™, Gmail™, Google Maps™, Google+™, Google Talk™, Google Cloud Messaging, Google Voice Search™, YouTube™)
Power	AC charger (24W; 12V/2A, 100-240VAC; 50 / 60 Hz) Lithium-Polymer smart battery (3.7V, 7600mAh) (up to 10 hours of battery life)[ii] Charging time: Sleep mode, approx. 6 Hrs.
Field Service Features	GPS: SiRFstarIV™ [iv] HD Web camera 5M pixels auto focus camera E-compass G-Seneor Optional 1D/2D Imager Barcode reader Optional 13.56MHz RFID and contactless smart card reader (ISO 15693 and 14443 A/B compliant)
GPS Sensor Specifications	Chipset: SiRFstarIVTM Receiver Type: L1 (C / A) Channels: 48 channels all-in-view tracking Update Rate: 1 Hz Horizontal Accuracy: i) Autonomous: 2.5 m / 8.2 ft ii) DGPS: 2.0 m / 6.56 ft Cold Start Time: 35 sec average Warm Start Time: 35 sec average Hot Start Time: 1 sec average Reacquisition: 0.1 sec average
Rugged Features	MIL-STD-810G and IP65 certified Optional ANSI/ISA 12.12.01 Vibration resistant Drop resistant (26 drops from 1.82m / 6ft) Optional EU Explosive Atmosphere ATEX Certified[v]
Environmental Specifications	Temperature: - Operating: -20°C to 50°C - Storage: -40°C to 70°C Humidity: - 95% RH , non-condensing
Security Features	WiFi for WPA / WPA2 operation Authentication: OPEN, SHARED-KEY, PEAP Encryption: WEP, AES, TKIP Native software encryption, root protection, IPSec VPN, software security support, network proxy settings, password security (PIN, pattern, password)
Dimension (W x D x H) & Weight	21.8 x 14.2 x 2.7 cm 800 g [iii]
Accessories	AC charger Quick start guide Capacitive stylus and tether Wrist strap Hand strap Office dock Vehicle dock Magnetic stripe reader and smart card reader Vehicle charger Carry bag Shoulder strap USB to RS232 converter cable Docking connector to HDMI converter cable Protection film

Z710 Configuration

	Specification				
	Storage Memory		*WWAN*	*Data Capture*	
	16GB	*1GB*	*HSPA+*	*2D Barcode*	*HF RFID*
Z710 Basic	•	•			
Z710 Premium	•	•	•		
Z710 Premium-2D	•	•	•	•	
Z710 Premium-RF	•	•	•		•

i. Software may vary depending on configuration.
ii. Battery performance will vary with software applications, wireless settings, power management settings, LCD brightness, customized modules and environmental conditions. Battery life and charge cycles vary by use and settings.
iii. Weight varies from configurations and optional accessories.
iv. Precision and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions.
v. The ATEX configuration, Z710-Ex, is certified for use in hazardous location zone 2 / 22. For more details, please visit Getac website.

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MioWORK™

L70

Rugged computing for Fleet management and Retail & Hospitality

The L70 series from MioWORK featuring an IP67 resistant design, and long battery life. The L70 series is with built-in GPS receiver and 3G* connectivity allowing for real-time vehicle tracking the two-way job dispatch. The L70 series integrates various data capture (NFC*, Camera) in a compact device, improve productivity in retail store, hotels and restaurant.

Comprehensive Using Scenario

Designed for multi-scenario, including :
Retail, Field Service & Utility, Fleet Management

Comprehensive Accessories

Fleet management cradle and suction cup for the usage of windshield and dashboard.

Connected Anywhere

Connectivity with 3G*
WiFi and Bluetooth® 4.0, NFC

Robust design

- IP67 sealing
- 1m drop resistant (concrete)

* Optional

MioWORK™

Specifications L70/L73/L75 L73R/L75R

	L70/L73/L75	L73R/L75R
Display	7" WSVGA 1024x600 IPS (400nits / 650nits*)	7" WSVGA 1024x600 IPS (400nits / 650nits*)
Touch Panel	Capacitive Multi - Touch Screen, support glove and passive pen	Capacitive Multi - Touch Screen, support glove and passive pen
Platform	ARM Cortex-A9 dual core (TI 4430 1G Hz)	ARM Cortex-A9 dual core (TI 4430 1G Hz)
OS	Android 4.2.2	Android 4.2.2
Memory	Mobile DDR2 1GB	Mobile DDR2 1GB
Storage	16GB; MicroSD up to 64GB	16GB; MicroSD up to 64GB
Wireless Interface	WWAN module* : UMTS/HSPA/GPRS/EDGE	WWAN module* : UMTS/HSPA/GPRS/EDGE
	- UMTS: 850/900/1700/1900/2100	- UMTS: 850/900/1700/1900/2100
	- GSM Full Bands: 850/900/1800/1900	- GSM Full Bands: 850/900/1800/1900
	- U-blox Lisa U200	- U-blox Lisa U200
	WiFi 802.11a/b/g/n	WiFi 802.11a/b/g/n
	Bluetooth 4.0, support BLE	Bluetooth 4.0, support BLE
	GPS + AGPS*	GPS + AGPS*
	NFC*, sensor on front cover	NFC*, sensor on front cover
Sensors*	Accelerometer (G sensor)- auto rotation	Accelerometer (G sensor)- auto rotation
	Ambient light sensor	Ambient light sensor
	eCompass	eCompass
	Vibrator	Vibrator
Camera	Front: N/A; Rear: 5M AF with flash LED	Front: N/A; Rear: 5M AF with flash LED
Physical Interface	miniUSB 2.0 - charging, PC Data Sync(client), OTG for extension module*	miniUSB 2.0 - charging, PC Data Sync(client), OTG for extension module*
	USB Type A 2.0 (host)	USB Type A 2.0 (host)
	MicroSD slot	MicroSD slot
	micro SIM card slot*	micro SIM card slot*
	3.5mm Audio Jack - support Headphone + mic	3.5mm Audio Jack - support Headphone + mic
	pogo pins connector on back cover to support cradle	N/A
	reserve holes for RAM mount capability on cradle	handstrap screw hold on back cover*
	Build-in MIC	Build-in MIC
	Build-in Speaker 1.5W x2	Build-in Speaker 1W x2
Buttons	Side: power, volume up/down, mute	Side: power, volume up/down, mute
	Front: camera, P1/P2/P3 function keys	Front: camera, P1/P2/P3 function keys
Battery	4000mAh battery	4000mAh battery
	Battery life - up to 8 hours (depend on user case)	Battery life - up to 8 hours (depend on user case)
LED indicator	N/A, charging status on screen	N/A, charging status on screen
Environment	IP67 and 1m drop resistant to concrete	IP67 and 1m drop resistant to concrete
	-10~+50°C operating temperature	-10~+50°C operating temperature
	-20~+70°C storage temperature	-20~+70°C storage temperature
	Humidity : 0~95%, Non-Condense	Humidity : 0~95%, Non-Condense
	Altitude : Operating: 0~15,000ft, non-operating: 0~40,000ft	Altitude : Operating: 0~15,000ft, non-operating: 0~40,000ft
Standard Accessory	Adaptor 5V/2A	Adaptor 5V/2A
	Power adaptor with power cord and plugs*	Power adaptor with power cord and plugs*
	USB cable	USB cable
Certification	CE/CB, FCC/IC, BQB, e-Mark	CE/CB, FCC/IC, BQB, e-Mark
Weight	535g	520g
Dimensions	H133.6mm xW218mm x D16.8/25.4mm	H133.6mm x W 218mm x H16.8mm

* Optional

Accessories

Fleet management

① **Car mount** | with vacuum suction cup
② **Fleet cradle** | one button release, support RS232, AV-IN, TMC, audio-out. charging
③ **Car charger** | Include TMC antenna, 5V/2A
④ **Fleet Cable** | with DB9 male connector

Others

① **Hand strap**
② **Stylus**
③ **Charging cradle** | IP57
④ **Car charger** | USB type A

MiTAC International Corp.

Description of the injection moulding process

The injection moulding process begins with the raw materials, which are polymer pellets and are usually bought in bulk.

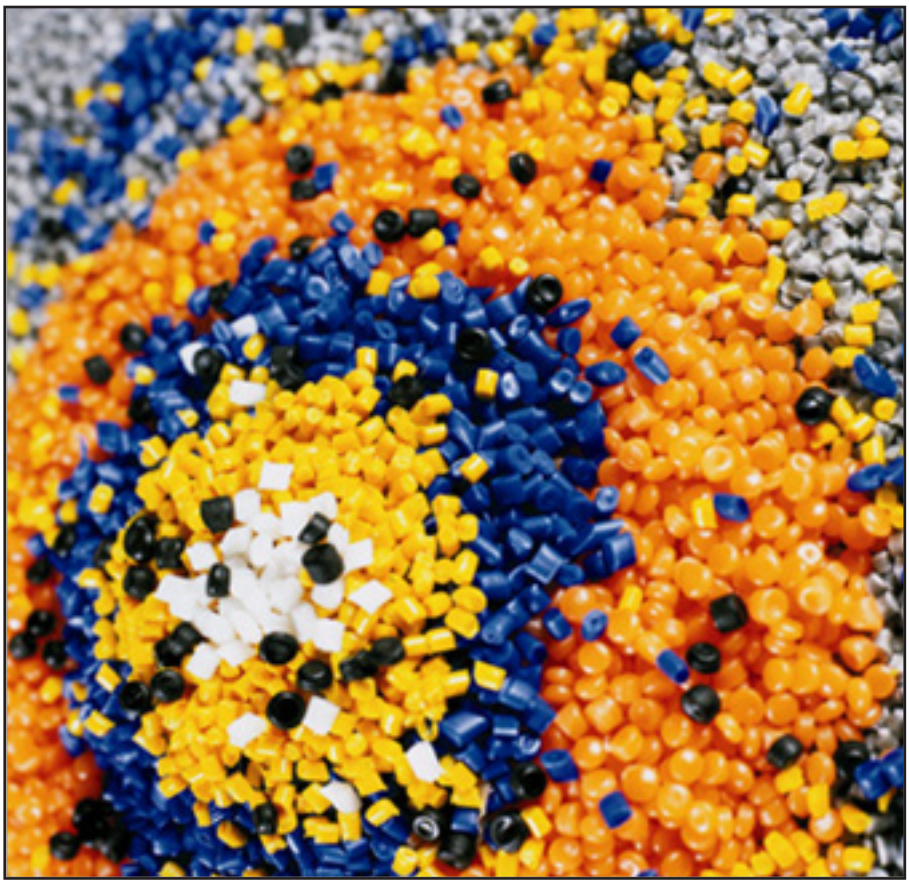

Figure 41. Coloured polymer pellets (Npl.co.uk, 2017)

The pellets are fed into an injection moulding machine, like the one shown in Figure 42.

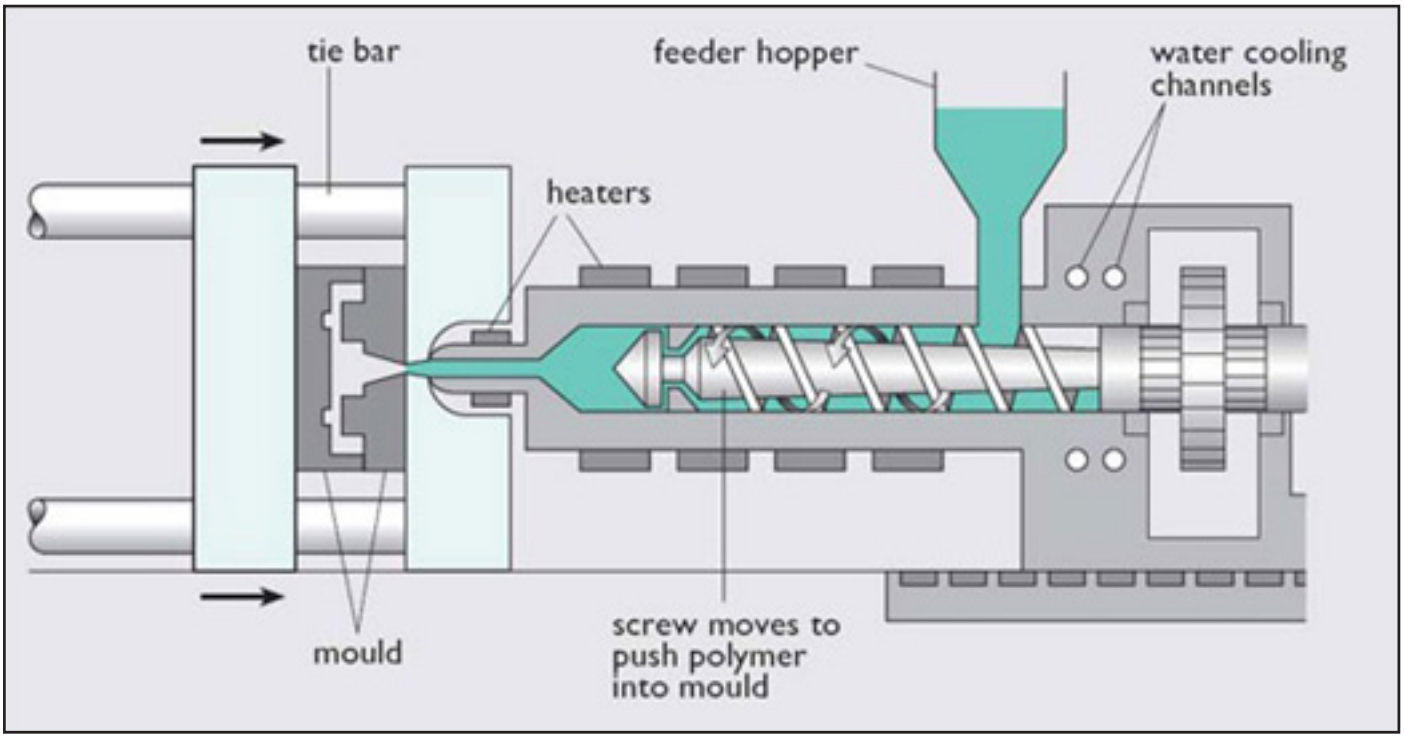

Figure 42. Injection moulding machine (Pentagonplastics.co.uk, 2017)

The process begins with the polymer pellets being fed into the feeder hopper. These pellets are heated up to a molten state. The temperature that the polymer is heated up to is dependent on the polymer type used. The molten polymer is forced under high pressure of approximately 10,000 to 30,000 psi, with a specified volume, known as a shot, injected into the mould to ensure there are no cavities in the mould due to underfilling and to prevent overfilling the mould (Plasticmoulding.ca, 2017). The injection can be done with a reciprocating screw such as the one in figure 2 which would be powered by either electrics or hydraulics, or with a hydraulic ram. The molten polymer is then cooled in the mould sometimes with the aid of water or air cooling, with the time taken dependant on the size and the complexity of the mould (Plasticmoulding.ca, 2017). Once cooled the part will be ejected from the mould using ejection pins that push the part away from the mould. The part will have runners attached to it and the number of runners is dependent on the size and the complexity of the part.

Location of manufacturing

Location is a key factor in the price of the manufacturing process. The cost of labour and the quality varies greatly from country to country. The manufacturing compensation costs for each country is shown below.

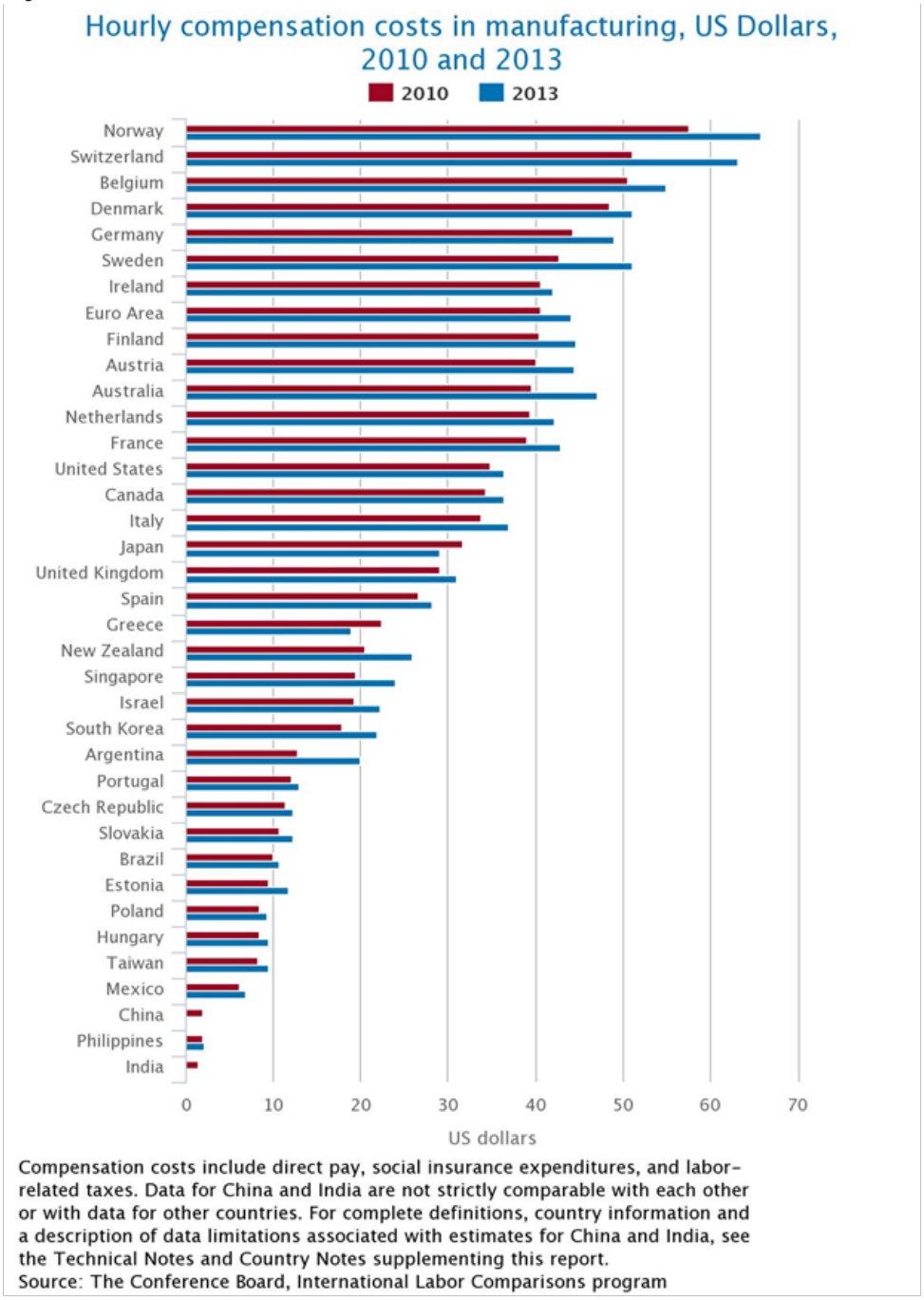

Figure 43. Manufacturing compensation cost by country (Conference-board.org, 2014)

Compensation cost can be used as an indicator of the cost of manufacturing in each country. From figure 2, it can be seen that Asia has the lowest costs of manufacturing, with Taiwan, China, India and the Philippines occupying 4 of the 5 lowest positions. Therefore manufacturing could take place there, especially since China has an established reputation for manufacturing, with it being the world's largest manufacturing economy with 22% of world manufacturing done in the country (Mapi.net, 2014).

Rank	% of World Manufacturing in 2012	2012	2002	1992
1	22.4	China	United States	United States
2	17.4	United States	Japan	Japan
3	9.7	Japan	China	Germany
4	6.0	Germany	Germany	Italy
5	2.8	Korea	Italy	France
6	2.4	Italy	United Kingdom	United Kingdom
7	2.3	Russia	France	China
8	2.2	Brazil	Korea	Russia
9	2.1	India	Mexico	Spain
10	2.0	France	Canada	Canada
11	1.9	United Kingdom	Spain	Brazil
12	1.8	Indonesia	Brazil	Mexico
13	1.8	Mexico	India	Korea
14	1.6	Canada	Indonesia	Turkey
15	1.4	Spain	Netherlands	Netherlands

Note: Valued in U.S. dollars
Source(s): United Nations and MAPI

Figure 44. World manufacturing rankings (Mapi.net, 2014)

Despite this, productivity in China is poor, scoring 14.2 compared to the USA's 68.2 and Germany's 43.3 (China.org.cn, 2014). This implies that manufacturing and assembly of the product in China may lead to poorer quality and reliability compared to producing it in an EU country or the USA.

Injection Moulds

The moulds are the most important part of the injection moulding process since they determine the quality and finish of the part. The moulds can be constructed using a variety of materials, normally metals in order to withstand the high stresses that occur under injection pressure. The material used is dependent on factors such as the number of cycles (number of parts produced), cost, and quality. There are classifications that estimate the lifespan of moulds, the SPI mould classification. The different classifications are shown in Table 3.

Type	Cycles	Descriptions
101	1 million+	High production moulds that also require the largest investment due to high quality tooling materials that can withstand the large number of cycles.
102	Up to 1 million	High quality mould with high price, used for parts requiring good tolerances.
103	< 500,000	Medium production mould in the most common price range
104	<100,000	Used for limited production.
105	<500	Designed to produce a small quantity of products, such as prototypes.

Table 3. Injection Moulds

Since the current Doble PDS100 sells at low volumes, of 100 units per annum in the UK and 1000 each in the USA and the EU, worldwide production and demand for the new product will be similar and would likely require a type 104 mould. A type 104 mould can be made from either aluminium or mild steel (Borgerson, 2017).