Advanced rescue detector

- Design and development of an improved rescue antenna

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Lavinräddningsdetektor

– Design och utveckling av en förbättrad räddningsantenn

Olle Berg

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Godkänt	Examinator	Handledare
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Sammanfattning

RECCO Rescue System är utvecklat och framtaget för lavinräddning och används av mer än 700 räddningsorganisationer runt om i världen för att hitta begravda lavinoffer och saknade personer. Systemet består av två delar: en passiv reflektor som är integrerad i kläder, pjäxor, hjälmar och skydd burna av skidåkaren; och en aktiv detektor som används av de organiserade räddningspatrullerna.

Sen 2009 har den aktiva delen i RECCO-systemet bestått av en handhållen detektor kallad R9. Den kan enkelt bäras av en räddningsarbetare som rör sig till fots eller i en helikopter och har en räckvidd på mer än 200 meter. Från att ha varit en stor, tung och opraktisk apparat har detektorn gått igenom en stor utvecklingsprocess sedan starten. Den första detektorn hade en lång antenn, som skapade en väldigt exakt antennlob, men när detektorn blev mindre blev också antennen förminskad. Det har fört med sig att antennloben har blivit mindre exakt och noggrannheten har därför minskats.

Nästa generations detektor, kallad R10, kommer att baseras på existerande R9, men behöver utrustas med en längre antenn. Då den ska vara i samma storlek som R9, kommer antennen behöva vara utfällbar. Det problemet har gett följande mål för den här examensrapporten: med hjälp av en passande utvecklingsprocess; förbättra antennen på RECCOs R9 detektor genom att förlänga den och därmed ge den bättre noggrannhet, men samtidigt hålla den praktiskt och robust, samt att göra den produktionsredo.

Projektet utfördes med hjälp av en spiral utvecklingsprocess uppdelad i 6 faser, där olika metoder, passande för projektet, var integrerade i varje fas. Mycket tid spenderades på 3D-modellering och prototyptillverkning för att testa och validera olika koncept.

Resultatet av examensarbetet är en radikalt ändrad och produktionsredo antenndesign. Antennen har roterats 90 grader samt dubblats i längd vilket ger den en bättre söknoggrannhet; trots det är det fortfarande en praktiskt och robust design som han hantera de tuffa kraven som en lavinolycka kräver. Lösningen består av ett delbart tredelars system som hålls ihop av ett gummiband, och sitter fast i detektorn med ett snäppfäste.

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Approved	Examiner	Supervisor
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Abstract

Developed for avalanche rescue, the RECCO Rescue System is used by more than 700 rescue organizations around the world to find buried avalanche victims and missing people. The RECCO system consists of two parts: a passive reflector integrated into clothing, boots, helmets, and body protection worn by skiers and riders; and an active detector used by organized rescue teams.

As of 2009 the active part of RECCO system now utilizes a small hand-held detector named R9, which can easily be carried by one rescuer travelling on foot or from in a helicopter and has a range of more than 200 meters. From being a big, heavy and unhandy device the detector has gone through an extensive development since the start. The original detector had a long pointing antenna which created very accurate antenna beams but since the device has become smaller, so has the antenna. Therefore, the antenna beams have become less directional, and consequently the accuracy has decreased.

The next generation of detectors, called R10, will be based on the existing R9, but needs to be equipped with a longer antenna. Keeping the same size as the R9, the antenna needs to be extendable. This problem lead to the following goal for this master thesis: by the use of a sufficient development process; improve the antenna of RECCO's R9 detector by increasing its length to give it a better search performance, but still keep it practical and robust.

The project was implemented with a spiral development process divided into 6 phases, where different methods suitable for the project were integrated. A lot of time and focus were spent on 3D-modelling and rapid prototyping for concept testing and validation.

The result of the thesis is a radically changed, production ready, antenna design. The antenna has rotated 90 degrees as well as doubled in length, giving it a better search performance; although it is still a practical and robust design that can handle the tough requirements that an avalanche situation demands. The solution consists of a divisible three part system that is mounted together with a rubber cord, and connected to the detector with a snap fit system.

FOREWORD

The master thesis project was performed in collaboration with RECCO AB and the Royal Institute of Technology. The project is representative of the final course in the authors´ education within Industrial Design.

The authors would like to extend their most sincere gratitude towards the persons that have supported and helped the project to advance. To our supervisor at RECCO, Magnus Granhed together with Lennart Brugge, we would like to express our deepest appreciation for all your help and inspiration during the project, and for the opportunity to do our master thesis at your company. To our supervisor at the Royal Institute of Technology, Carl Michael Johannesson we would like to thank you for guiding us in our work, questioning and giving us new perspectives of the project.

We would also like to thank Mälarplast that have provided us with comments about manufacturing, and other persons involved in the project in different ways.

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Johan Bergström

Stockholm, August 2014

Below are explanations for the abbreviations used in the report.

Abbreviations

ABS	Acrylonitrile butadiene styrene
CAD	Computer aided design
CNC	Computer numerical control
EM	Electromagnetic
FDM	Fused deposition modelling
FEM	Finite elements method
IMD	In mould decoration
PMMA	Polymethyl methacrylate
POM	Polyoxymethylene or Acetal
PC	Polycarbonates
RF	Radio frequency
SLS	Selective laser sintering
Ul	Unit less
VOC	Volatile organic compounds
QFD	Quality function deployment

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1. Introduction

In this chapter the background, purpose, goal and limitations for this master thesis project will be presented.

1.1. *Background*

The RECCO system was developed in response to a tragic avalanche accident in Åre on December 1973, which involved the founder Magnus Granhed. Magnus formed RECCO AB in 1980, today the detectors are standard equipment with more than 700 ski resorts, mountain rescue teams, and parks worldwide (RECCO AB, 2014).

The RECCO system consists of two parts: a passive reflector integrated into clothing, boots, helmets, and body protection worn by skiers and riders; and an active detector used by organized rescue teams. As of 2009 the active part of RECCO system now utilizes a small hand-held detector, which can easily be carried by one rescuer travelling on foot or from in a helicopter and has a range of more than 200 meters. The reflector contains a pair of foil aerials, joined by a diode. The size of the aerials makes the unit a tuned circuit resonating at one specific frequency and the diode generates harmonics when it is hit by the radar signal (Hirsch, 2012). The reflector is passive meaning it has no batteries and it never has to be switched on.

1.2. *Problem description*

Both the detector and the reflector have constantly been updated and improved since the beginning. They have become smaller and better for every update. The demand for better detectors is coming from the rescue teams that use them in searching and rescue missions around the world. They want the detector to be smaller, lighter, cheaper, more accurate and easier to use.

From being a big, heavy and unhandy device the detector has gone through an extensive development since the start. The latest version, the R9 detector, is only a fraction of the original size. The original detector had a long pointing antenna which created very accurate antenna beams but since the device has become smaller, so has the antenna. Therefore, the antenna beams have become less directional, and consequently the accuracy has decreased.

The next generation of detectors, called R10, will be based on the existing R9, but needs to be equipped with a longer antenna. Keeping the same size as the R9, the antenna needs to be extendable. This requires a smart but robust design, which this project aims to solve.

1.3. *Purpose*

The project will investigate and look into possible methods to place a new longer antenna on the RECCO detector. The new antenna needs to be more precise in search performance than the existing one by being about twice the length, but still be foldable, robust and easy to use. The project will also look into the material and the manufacturing of the antenna.

Goal

The following sentence clarifies the goal of this master thesis;

The goal of this master thesis is to, by the use of a sufficient development process; improve and develop RECCO's R9 antenna by increasing its length to give it a better search performance, but still keep it practical and robust, as well as making it production ready.

1.4. *Delimitations & Constraints*

The delimitations of the project have been decided to allow the project to be feasible and correspond to 30 credits each for two students at master level during one semester. The master thesis is delimitated to focus on the mechanism that extends the antenna. The size and positioning of the directors will be the same as on one of RECCO's earlier detectors. Since the antenna design is a very complex structure that requires too much work to fit into this thesis.

1.5. *Methods*

The project was implemented with different scientific and proved methods which are presented in this chapter.

Development process

The development process was divided into 6 phases and was a spiral process. It is adapted from the Ulrich and Eppinger spiral product development process (Ulrich & Eppinger, 2004). The process is presented in Figure 1, and it shows how the Literature study continued parallel to the other phases. It also shows the iteration of implementation and testing & validation. The iteration was made to improve the concepts after they were tested and possible problems were recognized.

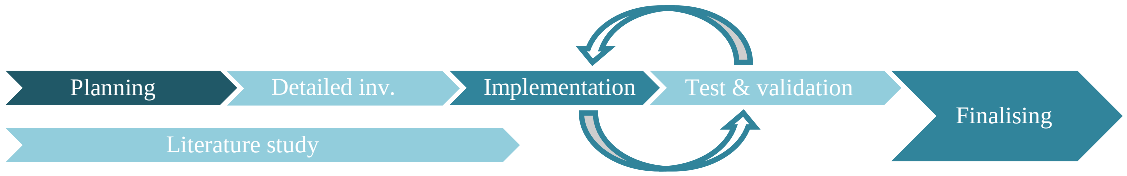

Figure 1. *The development process from Ulrich and Eppinger.*

Semi-structured interviews

A semi-structured interview is a mix between a structured and an unstructured interview. The semi-structured interview has a structure developed in advance on what topics to touch. However the interviewer may choose the order of questions and add supplementary questions (Osvalder, et al., 2008). The semi-structured interviews were used to collect information from RECCO, experts in antenna technology and experts in plastic manufacturing.

Quality Function Deployment – The House of Quality

Quality Function Deployment (QFD) is described by its developer Dr. Yoji Akao as a "method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process." (Akao, 1994). The QFD will be used in this project to give an overview over the demands and set units, goals, priorities and limits to the requirements.

Specification of requirements

When initiating a project, there is a significant importance in discovering and defining requirements. A project without defined requirements cannot anticipate what needs to be done and the extent of the work. There are two fundamentally different types of requirements; business requirements and product requirements (Alexander & Beus-Dukic, 2009). This project mainly looked at the later one, product requirements, since the goal was to improve a component in an existing product.

Brainstorming

Brainstorming is a method used to get started and generate a lot of ideas and solutions to the problem. The brainstorming in this project was being done according to Ullman's guidelines and rules which are:

1) Record all the ideas generated. Appoint someone as secretary at the beginning; this person should also be a contributor.
2) Generate as many ideas as possible, and then verbalize these ideas.
3) Think wild. Silly, impossible ideas sometimes lead to useful ideas.
4) Do not allow evaluation of the ideas; just the generation of them. This is very important. Ignore any evaluation, judgment, or other comments on the value of an idea and chastise the source.

(Ullman, 2010)

Concept testing and prototypes

Concept testing is a method which physically involves the client and/or user already in the development phase. Clients are often showed the concepts in ways such as rough sketches, models and prototypes and the concepts are explained in detail. It is important that the concepts are realistically and understandably explained for enabling the client and user to give proper feedback. The use of prototypes, models or sketches can generate a deeper understanding of the concept and are therefore preferable. (Kaulio, 1998) The method was used iterative and repeated several times during the development phase.

Pugh's method

Pugh's method was used to compare alternative concepts and choose which concept or concepts to further develop. The method provides a means of scoring each alternative concept relative to the others in its ability to meet the criteria. The decision-matrix method as it is also called consists of six steps as shown in Figure 2. (Ullman, 2010)

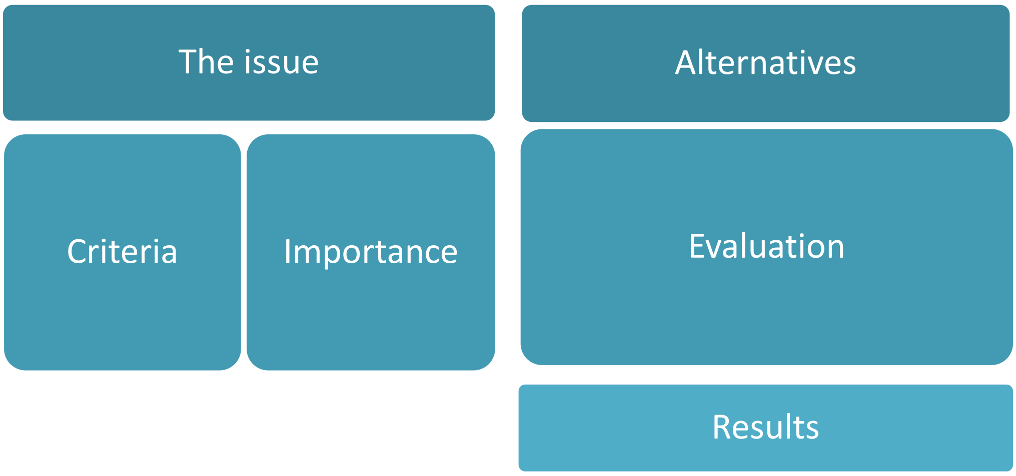

Figure 2. *The six steps of Pugh's method.*

Material selection method

One of the key responsibilities for design engineers is to choose the right material for their applications. In this project the material selection followed the method developed by Ulf Bruder in the book *Värt att veta om plast* (Bruder, 2011). The main elements in the method are:

- Use the knowledge from the company, manufacturer, tool manufacturer and material producer.
- Establish a comprehensive specification of requirements.
- Specify and sort material candidates.
- Determine a meaningful test program to simulate real conditions.

2. Pre-study

This chapter presents the background and the theoretical framework, which have been used during this project. The chapter aims to increase the reader's understanding of how a detector and its antenna are used and how they work.

2.1. *The RECCO System*

The RECCO system is a two part system with a passive reflector and an active detector. The reflector is integrated into jackets, pants, helmets, boots and body protection that is worn by skiers and outdoor hikers. The active detector is used by over 700 resorts and rescue teams all over the world. Utilized from major destination resorts throughout Europe, North America and Japan the RECCO system has been widely adopted as an additional tool to aid the search. As of 2014 there are no competitors to RECCO on passive rescue systems (RECCO AB, 2014)

The Reflector

In Figure 3 below one of the RECCO reflectors is illustrated. The measurements for this reflector is about 50x10x6 millimeters and the weight is 4 grams. Inside the black plastic cover there are a pair of foil aerials, joined by a diode. The size of the aerials makes the unit a tuned circuit resonating at one specific frequency and the diode generates harmonics when it is hit by the radar signal. RECCO's detector is sending out the frequency around 900 MHz to the reflector which then duplicates that frequency to around 1800 MHz and sends it back to the detector. The frequency differs around the world depending on what assigned frequency band RECCO has.

Figure 3. *One model of RECCO's integrated reflectors* **(RECCO AB, 2013)**.

The Detector

From being a big, heavy and unhandy device the detector has gone through an extensive development since the start. The latest RECCO detector on the market is called R9 and it is the 9^{th} generation, it can be seen in Figure 4 below. The handheld radar device operates with a transmitter and reciever to find the location of the reflector.

Figure 4. *The 9^{th} generation of RECCO detectors* **(RECCO AB, 2013)**.

It can easily be carried by one rescuer travelling on foot or in a helicopter and has a range of more than 200 meters in air and about 30 meters in snow. It is foldable and can be placed in a bag to ease during transportation and minimize the space for storage, see Figure 5.

Figure 5. *The R9 detector in its bag.*

To use the detector the rescue worker has to take it out of the bag and fold it up. The handle folds out of the back from the detector as seen in Figure 6.

Figure 6. *How to unfold the handle on the R9 detector.*

After the handle the user flips up the antenna on the front of the detector as seen in Figure 7 below.

Figure 7. *How to flip up the antenna on the R9 detector.*

2.2. *The Antenna*

Since the focus in this project is to improve the antenna in the detector a more thoroughly investigation of the theory behind the antenna was made. There are two antennas on the detector and the one that will be improved in this project is the outgoing antenna. That antenna is partly visible from the outside of the detector. It is the grey plastic piece on the front of the detector that the user flips up, see Figure 7.

Yagi Antenna

The antenna used for the outgoing signal in the RECCO detector is a Yagi antenna. Yagi antennas, sometimes called the Yagi-Uda RF antennas, are widely used where gain and directivity are required from a radio frequency, RF, antenna design. The Yagi antenna derives its name from its two Japanese inventors Hidetsugu Yagi and Shintaro Uda. It was first presented in 1928 and has since then grown rapidly to the stage where today a television antenna is synonymous with a Yagi antenna. (Joseph, 2001)

The Basics

A Yagi antenna design has a dipole as the main radiating or driven element. Further elements are added to re-radiate their signals in a slightly different phase to that of the driven element. In this way the signal is reinforced in some directions and cancelled out in others. There are three types of elements within a Yagi antenna, (Joseph, 2001):

- ***Reflector:*** The reflector is positioned furthest back on the antenna and is there to reflect the signal from the driven element in the forward direction.
- ***Driven element:*** The driven element in the RECCO antenna is a folded dipole. This is the element to which power is applied.

- ***Director:*** The directors are placed in front of the driven element. They are the ones that are visible from the outside of the RECCO detector, see Figure 8. On the R9 detector there are three directors and on the earlier R8 model there are 5 directors. Each director will add around 1dB of gain in the forward direction, although this number reduces as the number of directors increases.

Figure 8. *Underneath the antenna the three aluminum directors are visible.*

The typical Yagi signal pattern consists of a main forward lobe and a number of spurious side lobes, see Figure 9. The biggest side lobe is the reverse lobe caused by radiation in the direction of the reflector. The other side lobes are caused by interference of electronics, humans and other various elements.

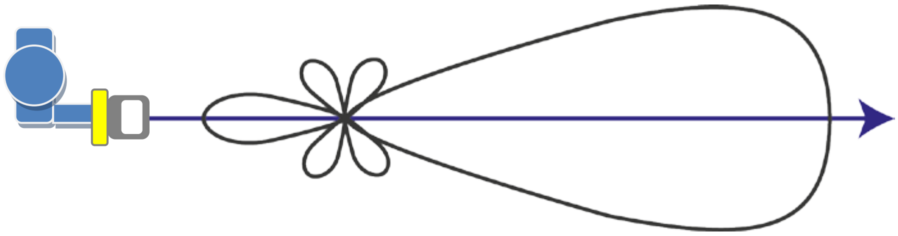

Figure 9. *A typically Yagi antenna pattern with the main forward lobe, a number of spurious side lobes and the reverse lobe. To the left is the rescue worker seen from top view.*

There are a number of possibilities to increase the gain in a Yagi antenna. Although it is found that as the gain increases the beam-width decreases, see Figure 10. To affect the overall gain the following could be changed, (Joseph, 2001):

- ***Number of elements in the Yagi:*** Adding more number of directors in the design is one of the main factors affecting the gain.
- ***Element spacing:*** The spacing between the elements is critical for better gain. Normally the positions of the elements are calculated by advanced computer programs.
- ***Antenna length:*** The overall length of the antenna has an effect of the gain. Generally the gain is proportional to the length of the array.

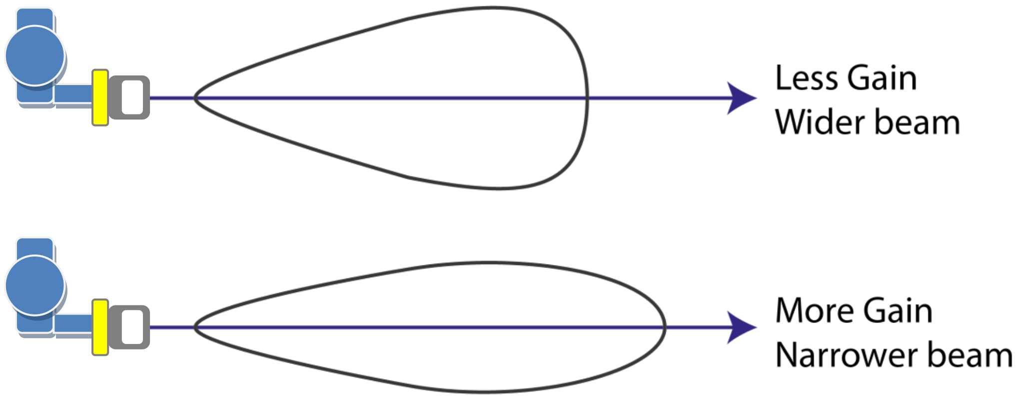

Figure 10. *Yagi antenna gain versus beam-width.*

External factors and influence on signal strength

The main concern when it comes to external factors, which influences the signal strength, is water. The more water the snow contains, the more it influences the signal strength. Water molecules absorb all radio waves including the radio waves from a RECCO detector. This is due to the electromagnetic absorption by water.

The water content of newly fallen snow ranges from about 5% when the air temperature is -15° C, to about 16% when the temperature is 0°C (Judson & Doesken, 2000). After the snow falls its density increases due to gravitational settling, melting, wind packing, and recrystallization. This is why, especially during sunny springs, the snow density becomes a big problem for rescue teams. On a sunny spring day the snow gets very wet. Data shows that the water content can be as high as 50% during spring and firn can reach 60 % (Judson & Doesken, 2000). On top of that avalanches compress the snow and increase the density even more. The density of avalanche snow can therefore vary a lot between fresh snow avalanches and late spring slab avalanche. The average density of dry snow avalanche is 250 kg/m^3 (Dent, et al., 1998) but for a wet slab avalanche this number reaches 390 kg/m^3 (Lang & Brown, 2002).

Raindrops absorb and scatter radar signals, so less energy reaches the target and even less returns to radar as an echo. Hence, precipitation (rain, snow, hail etc.) in general and rainfall in particular affect the propagation of electromagnetic (EM) waves (radar signals) in two ways: first, there is absorption of electromagnetic energy by water drops and vapor which causes radar signal attenuation (loss). Second, there is a returned signal from the rain which “clutters” the radar return and can mask targets. This phenomenon is known as rain clutter and strongly influences the radio wave scattering (Ulaby, et al., 1980).

These external factors make it even more important to increase the length of the antenna and therefore the signal strength.

2.3. *Current manufacturing*

The R9 detector is manufactured with injection moulding at the company Mälarplast. The assembling as well as placing of the directors in the antenna is done at RECCO.

Injection moulding and post processing

Injection moulding is undoubtedly the dominant processing method for polymer materials. The reason for this is that it has great cost benefits compared to other machining or moulding. The method has also gone through a big development and is today almost completely computerised.

Benefits with injection moulding:

- Often complete details can be produced in each shot.
- The details can have a complex design without any demands on finishing.
- High production rate.
- The thickness of the detail can shift from a tenth of a millimetre to more than 20 millimetres.
- It is relatively easy to combine and automate the production with post processing.

There are a couple of downsides with injection moulding though, the tools and machines are relatively expensive which demands a big serial size, minimum 1000 details. Another disadvantage is that the details shrink when they leave the mould, this can lead to tolerance problems.

The method used by Mälarplast to print the black logo on the front of the detector is called tampon printing. This is a cost efficient method do to prints on convex surfaces but it only works with darker colours than the surfaces have.

To do lighter prints on darker backgrounds in mould decoration (IMD) can be used. In this method a thin foil is placed inside the injection mould before the shot. IMD can create esthetical pleasing prints with a lot of details in a short amount of time.

(Bruder, 2011)

3. Detailed investigation

In this chapter the problem is more thoroughly investigated with the help of interviews and observations of the existing R8 and R9 detector.

3.1. ***R8 vs R9***

RECCO manufactured a detector R8 as the predecessor to R9, which has been presented above. When RECCO made the new R9 detector it was taken into consideration, that it would not have the same antenna qualities as the R8 detector. As RECCO made the detector smaller they had to place the electronics, cables and receiver closer to the outgoing antenna. Such a position affects the signal quality of the antenna. They also made the outgoing transmitting antenna shorter to fit to the smaller detector. As mentioned earlier, the length affects the signal quality detrimentally.

Size and weight

In avalanche-affected areas the snow is very uneven and there can be snow boulders that are meter high. The rescue worker may be forced to climb while carrying the detector. A smaller and less heavy detector is beneficial for a quicker searching. As seen in Figure 11 below the R8 detector is bigger than the R9. The R8 also weighs about 950 grams more than the R9 detector.

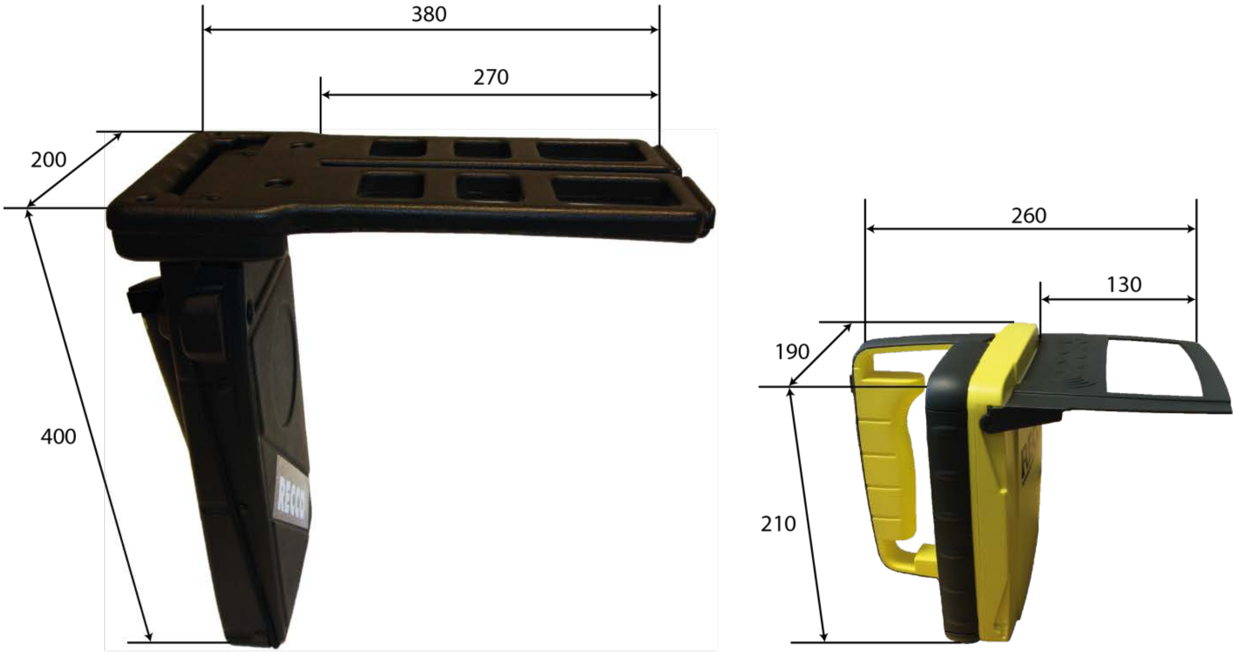

Figure 11. *A measurement comparison between the old R8 detector and the new R9 detector.*

Gain

One advantage the R8 has against the R9 detector with its size is that it has a bigger antenna. It can fit 5 directors in its antenna compared to the 3 directors that the R9 has. This gives the R8 antenna around 12 dB in gain compared to the R8's 9 dB in gain. As described in 2.2 *The Antenna* a higher gain also gives a narrower beam. This means that the R8 detector gives the rescue worker a more precise position of the victim.

Side lobes

Because of the bigger size of the R8 detector RECCO was able to place the electronics on the inside further away from the outgoing antenna. This leads to less radiation from the electronics that causes unwanted side lobes in the antenna pattern. Side lobes are unwanted since they can mislead the rescue worker to search in the wrong direction.

3.2. *Inside R9*

To understand the problem with the side lobes it is important to know how the inside structure of the R9 looks like. Figure 12 illustrates the R9 without its front cover and with a cut-out view. The picture shows the receiving antenna, the shielding plate and two parts of the Yagi antenna. The receiving antenna consists of two copper plates placed on the shielding plate. The electronics that includes batteries, buttons and circuits boards are placed behind the shielding plate to prevent the radiation to interfere with the receiver antenna and in some degree the outgoing transmitting Yagi antenna. As seen to the right in Figure 12 the electronics still cause some interference for the Yagi antenna since there is no isolation at the top of the electronics just below the reflector.

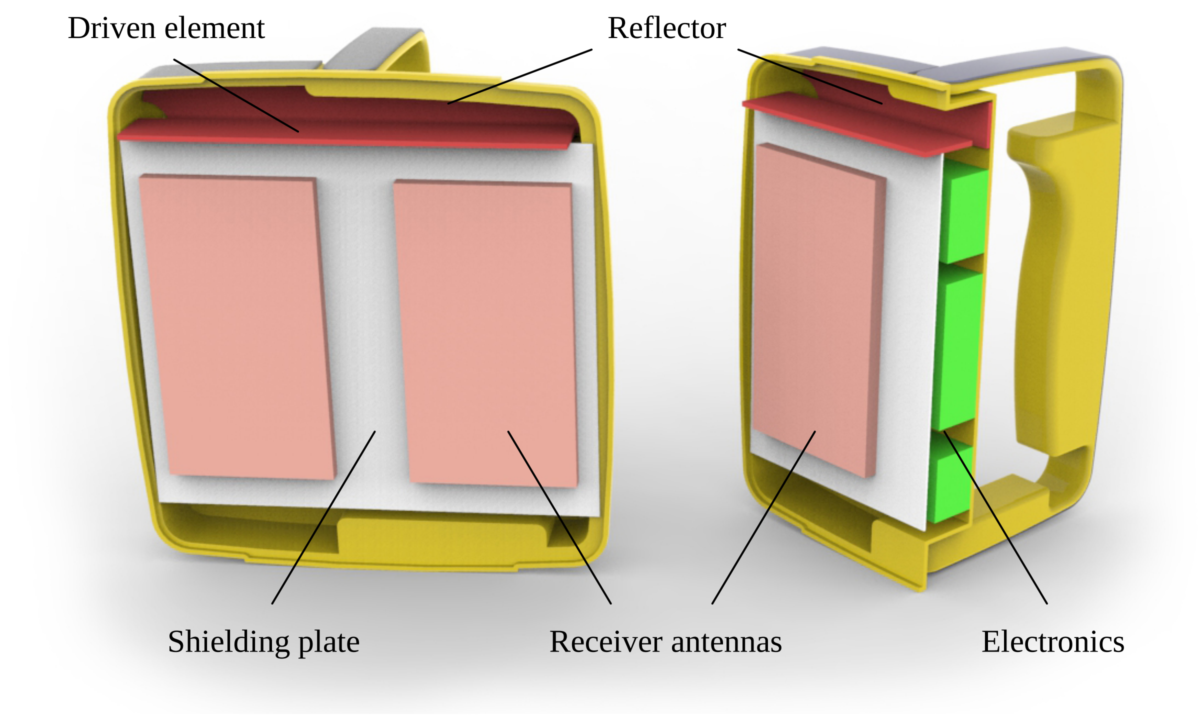

Figure 12. *The inside of the existing R9 detector.*

3.3. *The new R10 detector*

RECCO is planning on releasing a new detector within a year. They want their new upcoming R10 detector to have the same antenna length as the R8 detector so that they can fit as many directors on R10 as there are on the R8 detector. They also want to prevent the interference in R9 that comes from radiation of the electronics inside the detector. (Granhed, 2014)

RECCO's requirements

To improve the antenna qualities in the new R10 detector RECCO has two main requirements:

- ***Extendable antenna:*** The antenna should have the same length as the one on R8 but still be as portable as R9 when it is not in use. This requires some sort of foldable antenna.
- ***Repositioned antenna:*** To prevent the interference that comes from radiation of the electronics RECCO wants to reposition the antenna and have an isolation plate between the antenna and the electronics, see Figure 13.

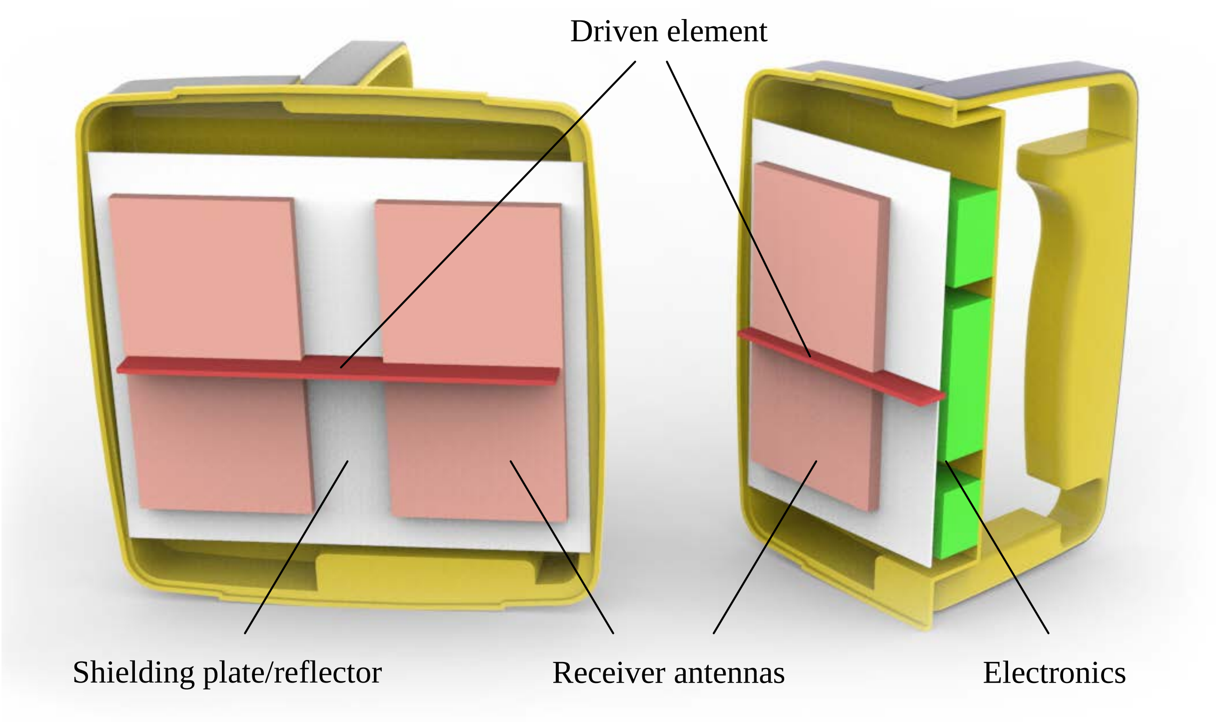

Figure 13. *The repositioned antenna on the middle of the detector.*

Furthermore RECCO have several additional requirements for the antenna on the new R10 detector:

- ***Helicopter down force:*** When rescue workers are using the detector from a helicopter there is a wind pressure from the rotor blades called down force. The antenna needs to be able to cope with this force without being folded down or broken.
- ***Withstand a fall:*** Since the terrain in an avalanche-affected area can be very rough it happens that the rescue workers falls and lands on the detector, in case of a fall it is important that the antenna will not break. On the R8 and R9 detector the antenna is removable and is attached to the detector with a rubber strap.
- ***Temperature differences:*** The antenna has to be able to cope with the temperature differences in the different environments that it is going to be used.
- ***No metal against metal:*** Metal against metal in the mechanics that extends the antenna will interfere with the antenna signals.
- ***Different sized directors:*** RECCO is using different frequencies around the world which means that to get the best signal they have different sized directors around the world. The antenna therefor needs to be flexible and fit different sized directors.

To see the full list of requirements that was made together with RECCO see Appendix I. The requirements were divided into project goal, must and should. The list of requirements does not define the limits or how to measure the requirements. The requirements will be transformed into technical requirements in a later stage.

(Granhed, 2014)

Quality Function Deployment

With the information from RECCO and the old R8 and R9 detector a Quality Function Deployment (QFD) house was done. This gives an overview of the user requirements and transforms them into design qualities with units, goals, priority and limits. The QFD can be seen in Appendix II.

Specification of requirements

From RECCO's requirements, interviews, the QFD and the literature study a full specification of requirements could be developed. The requirements were divided into 7 different kinds of requirements; communication-, user-, ergonomic-, technical-, economic-, production- and ecological requirements. Furthermore every requirement was given a verification method, a goal and was prioritized from 1 to 3, where 1 was small desirability, 2 was desirable and 3 was absolutely necessary. Lastly a limit was given to every requirement that the end product has to fulfil. For the full specification of requirements see Appendix III.

This chapter describes the development process from brainstorming to a selected concept and all the phases between that.

4.1. ***Brainstorming***

Brainstorming was used as the initial ideation method to start find solutions for the new antenna. Only the two authors participated but there were some ideas from RECCO that had been written down from earlier interviews. When communicating the ideas, both writing and sketching were chosen for use. The brainstorming went on for about 2 hours and resulted in hundreds of post it notes and sketches. After the 2 hours the ideas were discussed and new better final sketches were made of some ideas that were hard to understand due to quick sketches. Parts of the final sketching result from the brainstorming can be seen in Figure 14 and in Appendix IV. The text that was written down was more statements than concepts and some of it were:

- If the antenna is placed vertical instead of horizontal there will be a less down force from the helicopter on the antenna.
- An elastic rubber band is good to prevent the antenna to fly away in case of a fall.
- With less area on the antenna there will be less down force from the helicopter on the antenna.
- If the antenna can use the technique from an avalanche probe where the user pulls a handle to extend the probe the antenna could be unfolded really quickly, see Figure 2 in Appendix IV for an avalanche probe.

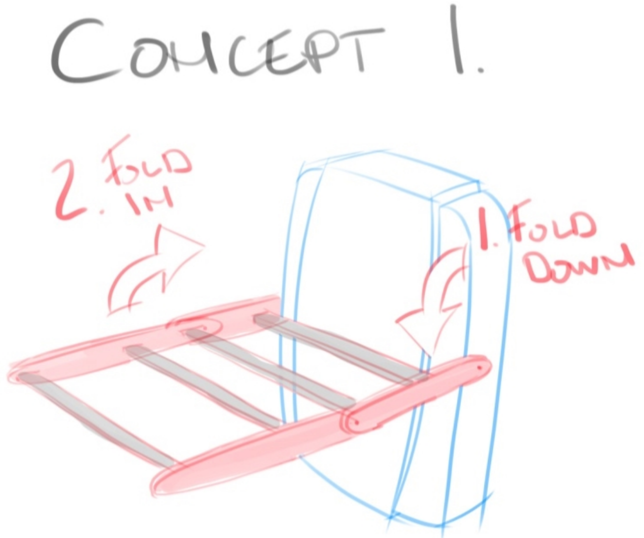

Figure 14. *One of the concepts from the brainstorming.*

Vertical antenna

One of the things that were brought up during the brainstorming was if the antenna could be positioned vertically instead of horizontal. This would decrease the amount of down force from the helicopter on the antenna, since there would be a smaller area for the wind to push on. K-G Forssén was contacted to confirm if the antenna could theoretical be placed vertically instead of horizontally. K-G is Technical Director for RECCO and is an expert on antennas. According to K-G there were no problems with placing the antenna vertical as long as the receiver antenna was in the same position. As seen in Figure 15 both the outgoing transmitting antenna and the receiver antennas are rotated 90 degrees. (Forssén, 2014)

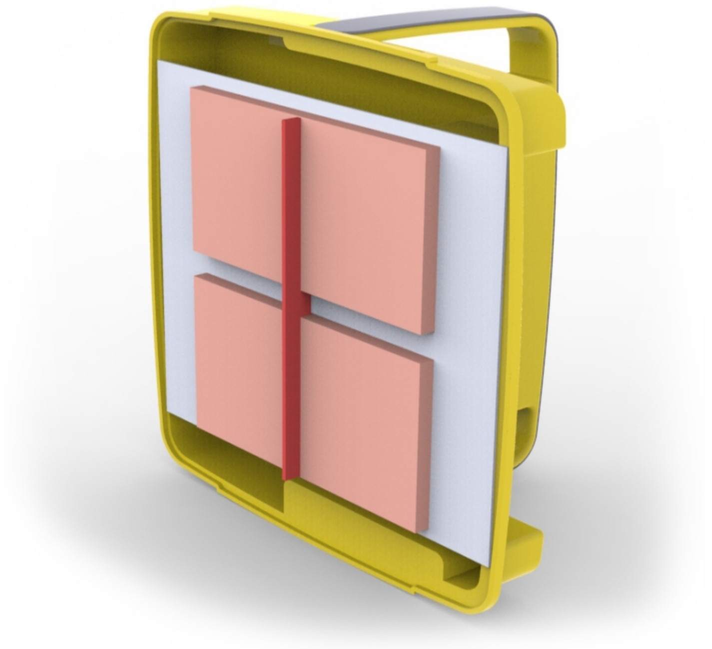

Figure 15. *Inside the R9 detector when both the outgoing and receiver antenna is rotated 90 degrees.*

First selection of ideas

To sort out some of the ideas from the brainstorming a Pugh's matrix was done with the most promising concepts seen in Appendix IV. The criteria for the evaluation were taken from the specification of requirements. They were ranked according to importance and the most important criteria got an importance of 20 and the less important 10. The goal with the selection was to narrow down the amount of concepts and evaluate them for future work.

According to the evaluation matrix that can be seen in Appendix V concept 3 is the superior one. Since the concepts were far from fully developed it were hard to assess some of the criteria and therefor there are two questions marks in the matrix. After a discussion it was decided that concept 5 was the one to stop develop since it had a low score and too many uncertainties about feasibility.

4.2. *2D-Models*

2D-models were made out of foam board and needles to illustrate and confirm the 5 different ideas selected from the brainstorming. 2D-models can be made relatively fast and the material foam board is cheap and easy to work with. These qualities were contributing factors to the choice of doing 2D-models in foam board. In Figure 16 model 5 is photographed from top view in its extended position, half folded and when it is folded. The black piece is the detector and the grey pieces are the antenna parts. All the models had the same size and were scaled to about 1:2. Appendix VI shows each model with a short information text.

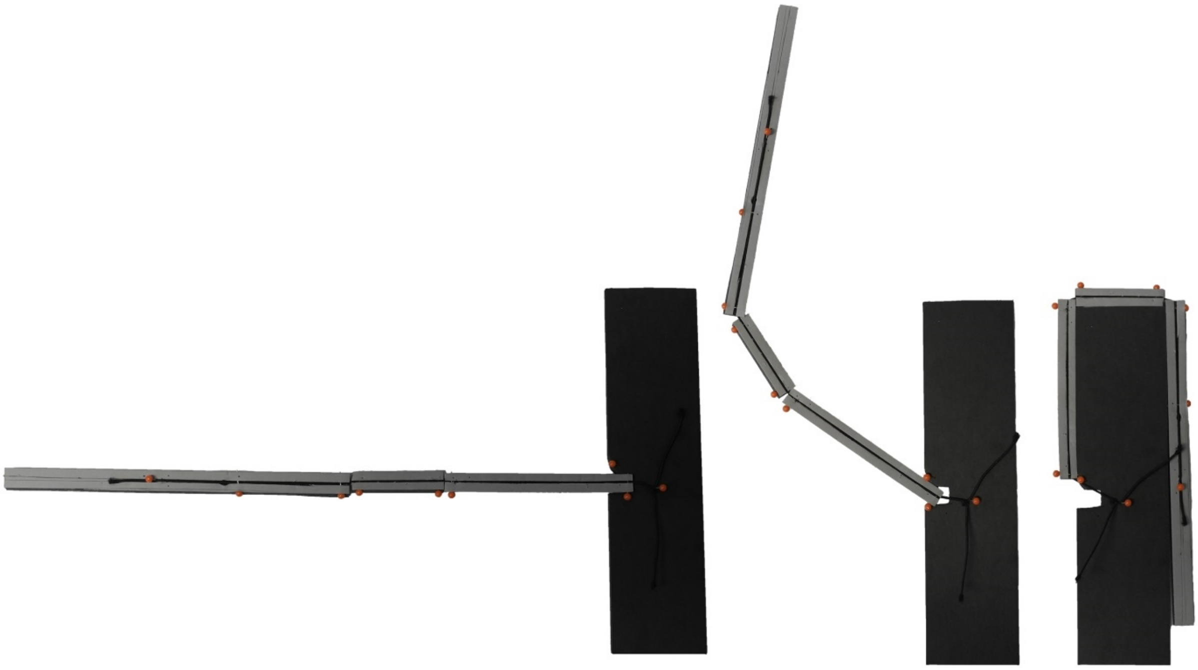

Figure 16. *Model 5 of the foam board models in top view.*

Second selection of concepts

In this phase two concepts were about to be chosen for further development, since there are two persons in the project, each could do one 3D-model of the chosen concepts.

With the 2D-models the concepts could be further tested and evaluated. To evaluate the concepts a new Pugh's matrix were done. This time the physical models and their performance formed the basis to fill in the matrix. The result can be seen in Appendix VII and shows that model 5 has the most potential and model 4 the least. The other models had the same weighted total but after a discussion it was decided that model 2 was the one to further develop. It was chosen since it has the proper length and is similar to the existing R9 antenna.

4.3. *CAD-Models*

With the two concepts chosen CAD-models could be done. The purpose with the CAD-models was to further develop, test and confirm the concepts. The models were done in both Solid Edge (Siemens Product Lifecycle Management Software Inc., 2012) and SolidWorks (Dassault Systemes, 2013) and the pictures have been rendered in Keyshot (Luxon Aps, 2013). The choice of programs was based on the authors´ knowledge and their computer capacity.

A lot of time was spent from the beginning to make the models feasible fulfilling requirements as well as manufacturability. With that in mind it took several iterations between prototyping and modelling, numerous discussions and many small improvements over a couple of weeks to complete them.

Sliding concept

Concept number 6, now named the sliding concept, is basically the existing antenna with an extension on it. It is divided into two parts were the first part looks like the existing antenna with the exception that it has a connection at the end for an extension. The antenna folds in as in Figure 17 below, the outer part folds up and the inner part slides up and folds down.

Figure 17. *The sliding concept unfolded, when folding and folded.*

The parts are connected both by mechanical locks as the sliding track and also by rubber bands as seen in Figure 18. The rubber band holds the antenna in position both in its extended position and when it is folded.

Figure 18. *Close up on the rubber band and sliding track.*

The inner part of the antenna is locked to the sliding rail in the detector with small pins as seen to the left in Figure 19. The extension is connected with the inner part by a mechanical lock, as seen to the right in Figure 19. It is the same kind of lock as the one that the R9 antenna is connected with.

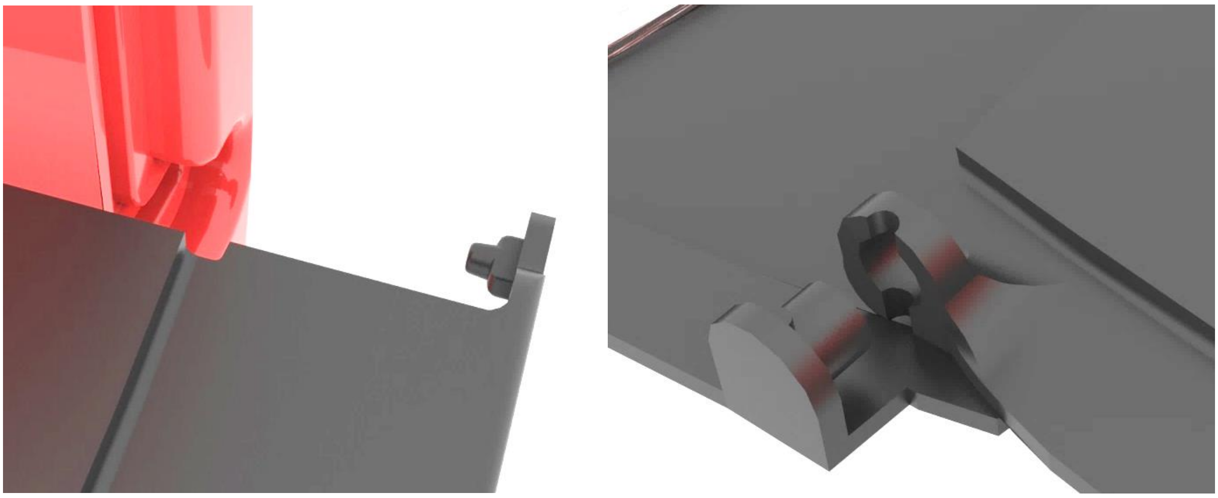

Figure 19. *To the left is the connection between the detector and the antenna and to the right between the two antenna parts.*

Snap fit concept

Concept number 3, now named the snap fit concept, is influenced by how avalanche probes works. When folded it goes around the detector and connects on the backside, see Figure 20. The name comes from the snap fit with which the antenna is connected to the detector. To fold the antenna the user unsnaps the antenna from the snap fit, pulls out the outer part to separate the three sections, folds the antenna around the detector and attaches it to the back of the detector on the outside of the handle.

Figure 20. *The snap fit concept folded, when folding and unfolded.*

The antenna is divided into three different parts connected by a rubber band and form locks with male and female parts as illustrated in Figure 21.

Figure 21. *The antenna when it is pulled apart, the rubber band is visible between the parts.*

The antenna is connected to the detector with two snap fits, one on the bottom and one on the top. In Figure 22 the top snap fit is illustrated. The snap fit is constructed so that if the rescue worker falls on the detector it will release and prevent the antenna from breaking.

Figure 22. *The top snap fit that connects the antenna with the detector.*

4.4. ***Prototypes***

To evaluate the two different concepts more thoroughly several different prototypes were made. The prototypes were made with both 3D-printers and milling machines. The prototypes were initially focusing on different details in functions of the concepts. For instance the sliding track design was changed as seen in Figure 23 when it was found that the "hook" at the top was not needed for the function. Several iterations like this were made between the CAD-modelling phase and the making of prototypes.

Figure 23. *Two different prototypes of the sliding mechanism, the left one is the initial design and the right one the improved.*

All the prototypes can be seen in Appendix VIII together with a more detailed manufacturing process.

4.5. *Final concept selection*

With two highly developed concepts a new final evaluation and selection could be made. As before Pugh's matrix was used. With more detailed concepts the criteria list could be longer. More requirements from the specification of requirements list were added to the matrix to make a better evaluation. Criteria that had been hard to evaluate before, such as low cost production or reduced weight could now be taken into consideration.

The result from Pugh's matrix, which can be seen in Appendix VIII, showed clearly that the snap fit concept was the best one. It was better in feeling robust, handling down force, withstanding a fall, water resistance, repositioning and easy to extend. It had some weaknesses compared to the sliding concept, namely that it is more difficult and more expensive to manufacture since it consists of more parts. To confirm that the snap fit concept was the one to continue develop a meeting with RECCO was set up. At the meeting the two different concepts were discussed and RECCO agreed that the snap fit concept was the better one. Their arguments were that it was smart to have it vertical, it looked more robust, it could protect the directors from water and it seemed easier to extend and fold. With both the Pugh matrix and RECCO showing the same result the decision to continue work with only the snap fit concept was taken. (Granhed, 2014)

In this chapter the finalizing of the snap fit concept with the material selections, manufacturing process selection, stress calculations and mould flow analysis is presented.

5.1. *Finalizing*

With the snap fit concept chosen as the final concept, the process of making it production ready started. It is as important to have a good, reliable design as to keep the focus on manufacturing ability.

Antenna

The antenna consists of a divisible three-part system that is mounted together with a rubber cord. Each of the three parts have place for either one or two directors. Placing the directors inside the plastic antenna instead of outside as with the R9 generates protection against weather exposure and scratches. Two parallel canals run through the whole antenna to make space for the rubber cord and to strengthen the design, see Figure 24.

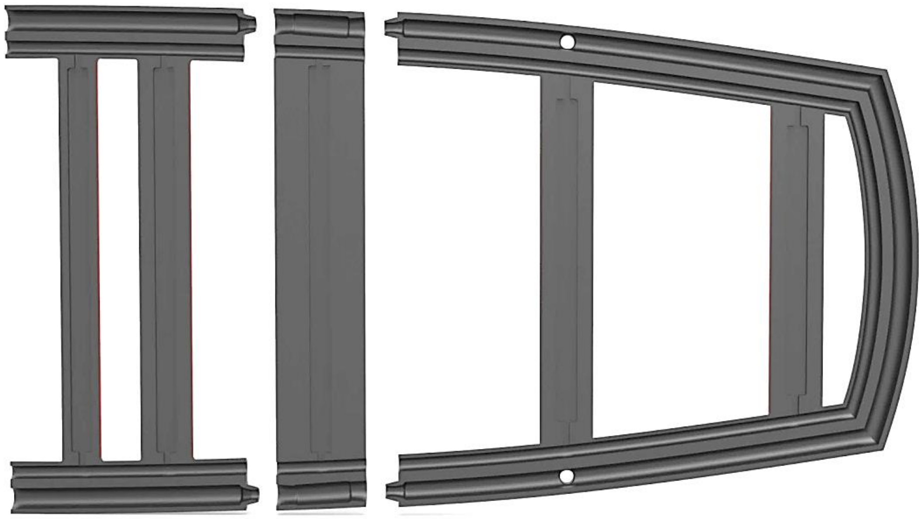

Figure 24. *Divisible three-part antenna in a cutaway view.*

The cavity for the directors suits different sized directors and therefore different frequencies. Before assembling together both sides of the antenna directors need to placed inside.

For ventilation purposes canals are fitted so that there is a connection between the cavities for the directors, marked blue, and the inner sweep canal, see Figure 25. It might seem to be a better idea to seal the directors to totally prevent moisture, but that would lead to corrosion on the directors after a certain time. Water and moisture diffusion in the plastic will get water into the cavities. Without a ventilation canal the water will remain in the cavities and corrosion will occur. If freezing the trapped water will expand and lead to cracks between the parts (Forssén, 2014).

Figure 25. *The ventilation canals between the blue directors and the inner sweep canal.*

The fitting system is developed to both provide stability for the antenna when extended, but also provide the antenna with flexibility for disassembling and to conquer with hits or mechanical shocks. In the event of a hit the fitting system releases instead of damaging the snap fit system. The rounded corners and 20° angled sides simplifies the assembly process, see Figure 26 for a close up illustration.

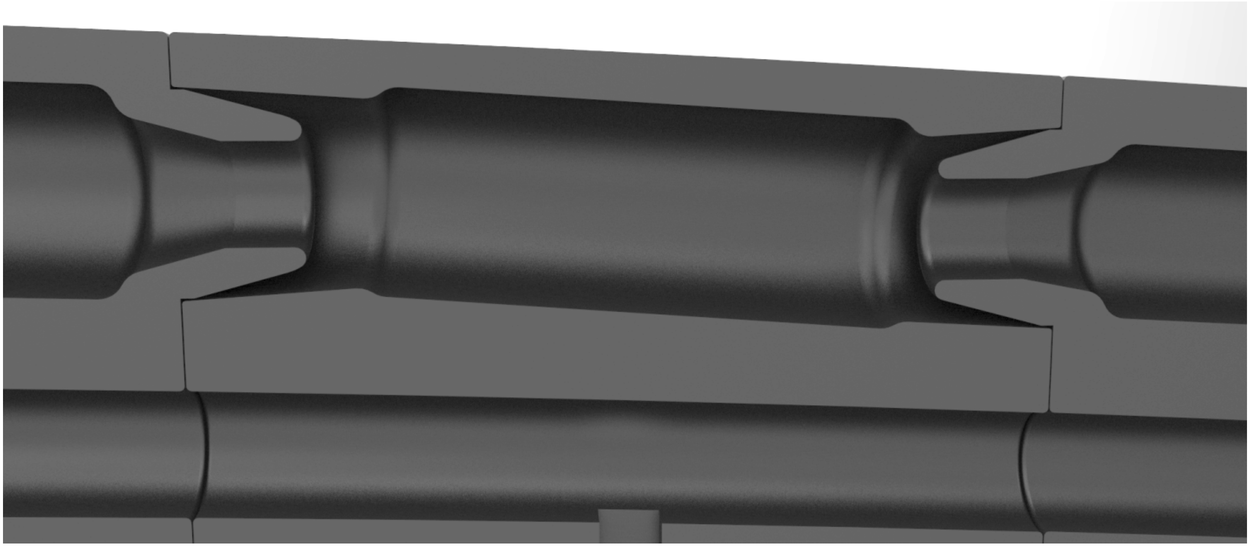

Figure 26. *Antenna fitting system in cutaway view without the rubber cord.*

To secure the antenna on the backside in folded position two solutions were made. One with a pocket in which the antenna slides when folded, see Figure 27. This solution is composed of an injection moulded pocket and three small screws to lock it in place. Nevertheless in cooperation with RECCO it was decided that this securing solution was too expensive, since it consists of multiple parts and an injection mould. Therefor a cheap and reliable solution with a hook and loop fastener was chosen. It will be placed on the short edge on the base module and secure the tip of the antenna.

Figure 27 *Antenna securing system for the folded position.*

Snap fit system

For the final design a complex snap fit was chosen to cope with challenges such as big temperature differences, hard falls, stormy wind gusts and demand for easy handling. As seen in Figure 28 the design consists of a two arms that hold on to the antenna (1), a supporting cavity (2) and two holes for the screws to mount the snap fit onto the director (3).

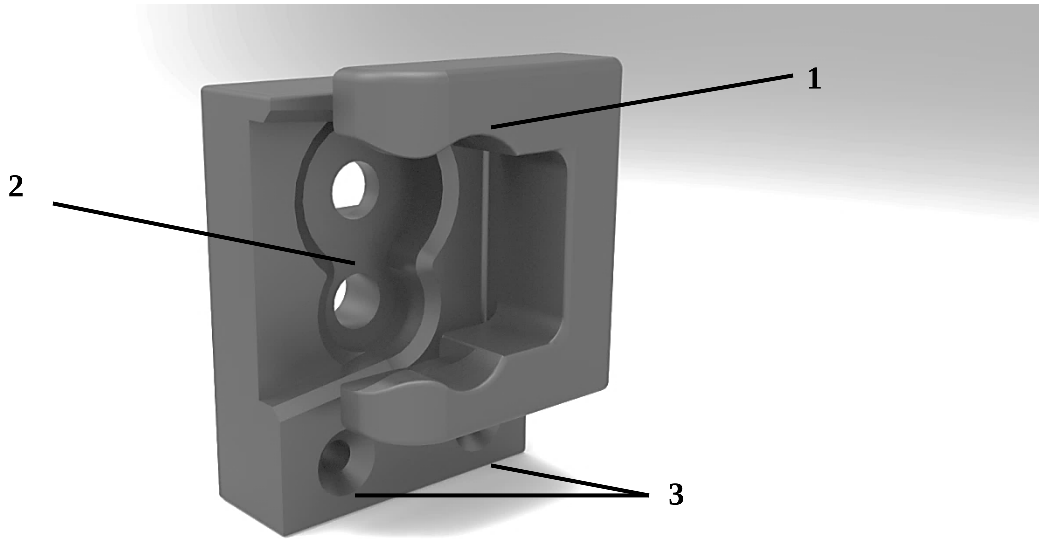

Figure 28. *The snap fit system. Snap (1), Cavity (2), Screw positions (3)*

The antenna fit in the final version, uses the SS-ISO 677 standard interference fit Ø12 P8/h7 with the axis as base, see Figure 29 (Björk, 2007). The cavity has more clearance since the antenna needs to be able to be release from its fixture when exposed to forces from a fall.

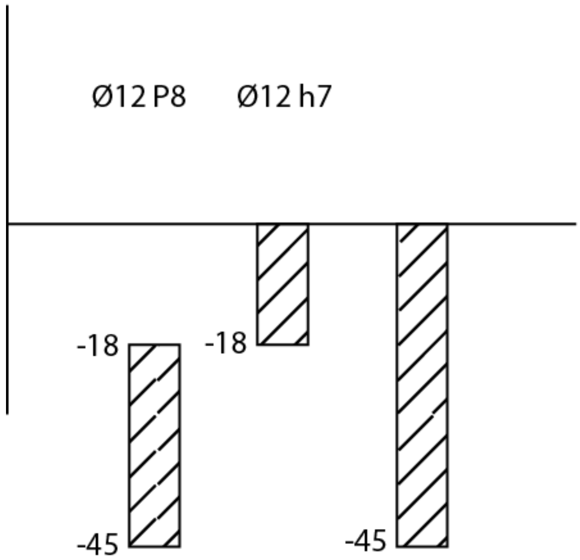

Figure 29. *SS_ISO 677 tolerance, Ø12 P8/h7*

When folded, the flat lying antenna slips into another cavity, marked blue in Figure 30. This helps the antenna getting in the right position for both storing and unfolding.

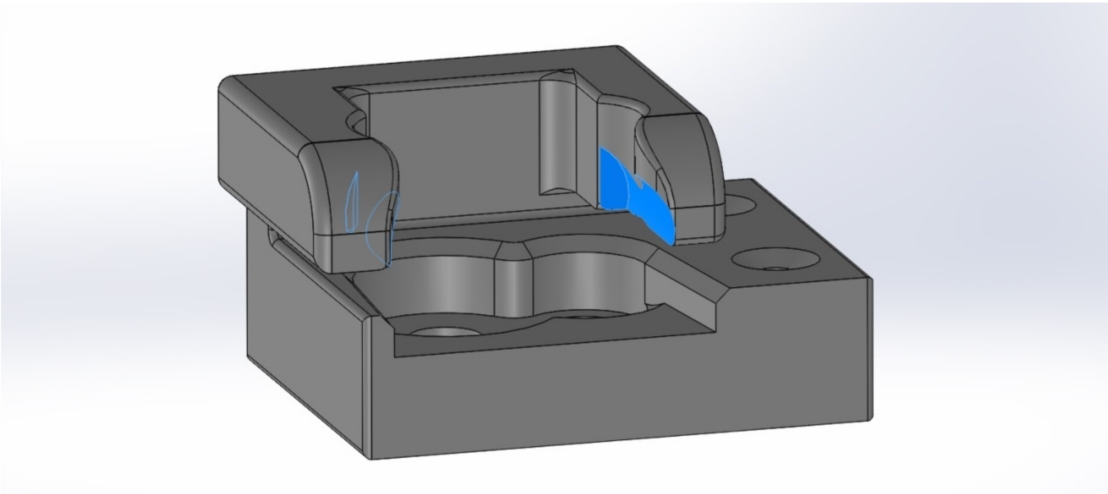

Figure 30. *Dedicated cavity (marked blue) for antenna in folded position*

Two non-metallic screws secure the snap fit in a fix position in the detector. In case of maintenance the system can easily be disassembled with this method. These screws can be made out of nylon or any other robust polymer depending on how the detector is designed.

The snap fit solution also provides the antenna with an ejection system. In case of a hard fall or a hit from the non-supported side the antenna can release itself from the snap fit without damaging any component, see Figure 31.

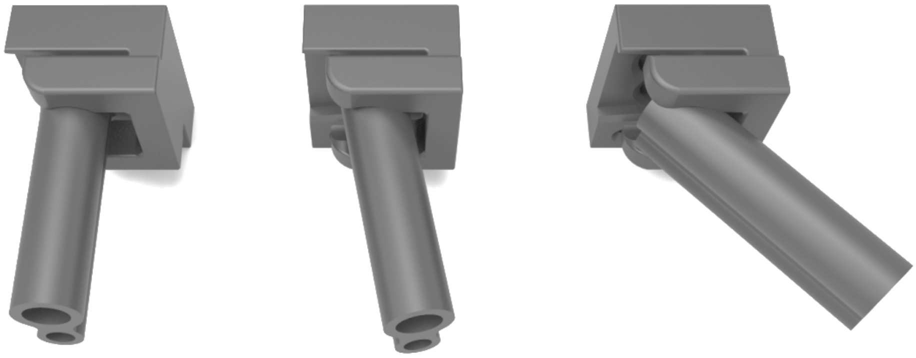

Figure 31. *Ejection system in case of fall.*

Contractive rubber cord system

The rubber cord is placed in the outer canal and runs through the snap fit and the three antenna parts to the plug, see Figure 32. The rubber cord has two functions; firstly it holds the parts together both when the antenna is extended but also when it is folded. Secondly it keeps the parts from getting lost in case of a fall during which the antenna is released from the snap fit.

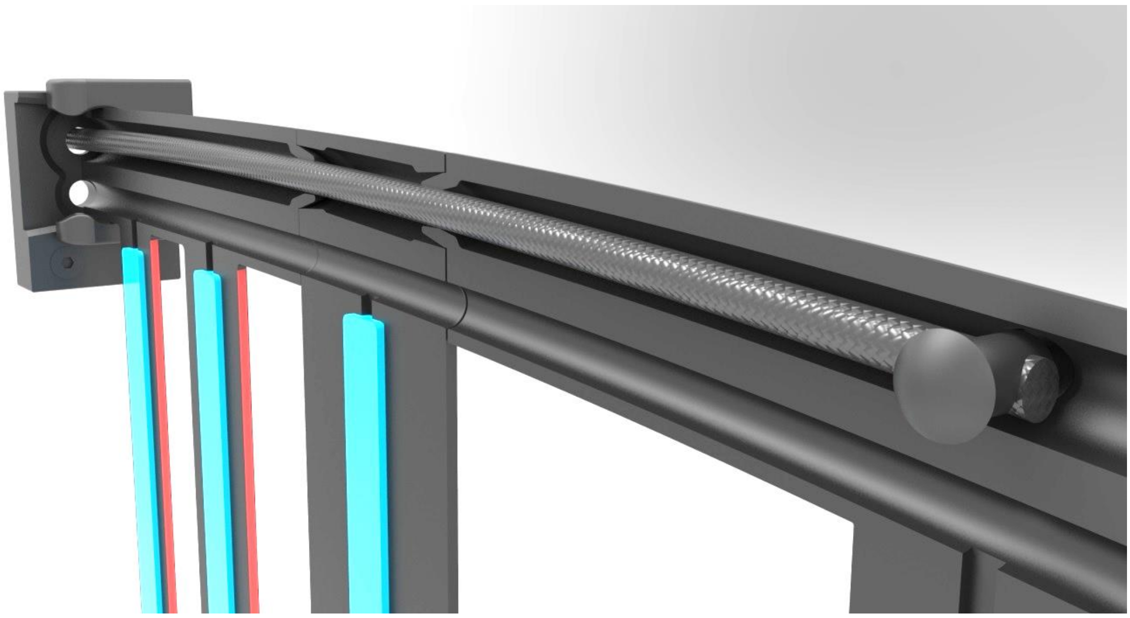

Figure 32. *Rubber cord placed inside the antenna in cross section view.*

In a first version the rubber cord was placed in the inner sweep canal. After reconsideration with RECCO (2014) it was decided to place the rubber cord in the upper sweep canal to enhance the mounting performance with the sliding fitting system.

5.2. *Material selection*

The material selection is an important part of the development. There are a lot of requirements on the material and with a poor choice of material the whole antenna could fail. It was decided from the beginning that the material would be some kind of polymer since it has a complex form, must be impact resistant and cannot be a conductor. The material has not only to withstand the forces it must do it within the temperature range that the detector faces. When transported from inside a house to outside on the mountain in just seconds there can be up to 60° Celsius in temperature differences. These demands lead the search into engineering plastics, which have better mechanical and thermal properties than the more widely used commodity plastics. (Bruder, 2011)

The old R9 detector and antenna is made of polycarbonate (PC) which is an impact resistant amorphous engineering plastic. According to RECCO the R9 detector has held together perfectly and they have not had a lot of broken antennas or detectors due to the material (Granhed, 2014).

When searching for the most suitable material mainly three different sources have been used; the book *Värt att veta om plast* (Bruder, 2011), the computer program *CES EduPack* (Granta Design Limited, 2013) and the manufacturer *Mälarplast* (Lindström, 2014).

In an email exchange with Mälarplast they thought that the snap fit should be made in polyoxymethylene (POM), also called Acetal. It is an engineering plastic were the mechanical characteristics are affected insignificantly in the temperature range of -40°C to +80°C and it has excellent spring properties. On the downside it is sensitive to predetermined breaking points, such as sharp corners. (Bruder, 2011)

In CES EduPack the different requirements on the material can be input to the program to find suitable materials. Since there already were two potential materials these were used to limit the search for materials together with the specification of requirements, see table 1 in Appendix X. With the search in CES EduPack the material Polymethyl methacrylate (PMMA) also showed up. Table 2 in Appendix X shows the properties for each and one of the three materials; PC, POM and PMMA.

PMMA, or Acrylic glass as it sometimes is called, is a transparent thermoplastic often used as a lightweight alternative to glass. The downsides with PMMA are that it is prone to scratching and behaves in a brittle manner when loaded. With scratches the antenna would feel less expensive or less professional which are two desirable requirements. Together with the disadvantage that it behaves in a brittle manner when loaded eliminated PMMA from the selection. (Bruder, 2011)

The material found most suitable for the antenna parts after the material selection method where PC. With the same method it was decided to make the snap fits in Acetal, thanks to its resilient and thermal properties.

5.3. *Manufacturing*

Parallel to the material selection different manufacturing processes were investigated. Both the R8 and R9 detectors have been manufactured by injection moulding. Together with RECCO it was decided that this was a preferable method since they already have a manufacturer that will continue to produce the rest of the detector. Further options could be vacuum forming, 3D-printing, blow moulding or rotational moulding, but these methods are not suitable for the antenna. They would not be able to produce the complex form of the antenna design in necessary manufacturing quantities (Thompson, 2012).

The whole antenna construction consists of 23 parts, seen in Figure 33. The six parts that are the actual antenna, red and black framework in the picture, consists of three different types. For manufacturing purposes the antenna is split in the middle along the vertical axel. The parts are symmetrical and they can be flipped 180° around the horizontal axel and fit together. This is to minimize the cost for production by having only three different moulds instead of six for the antenna parts.

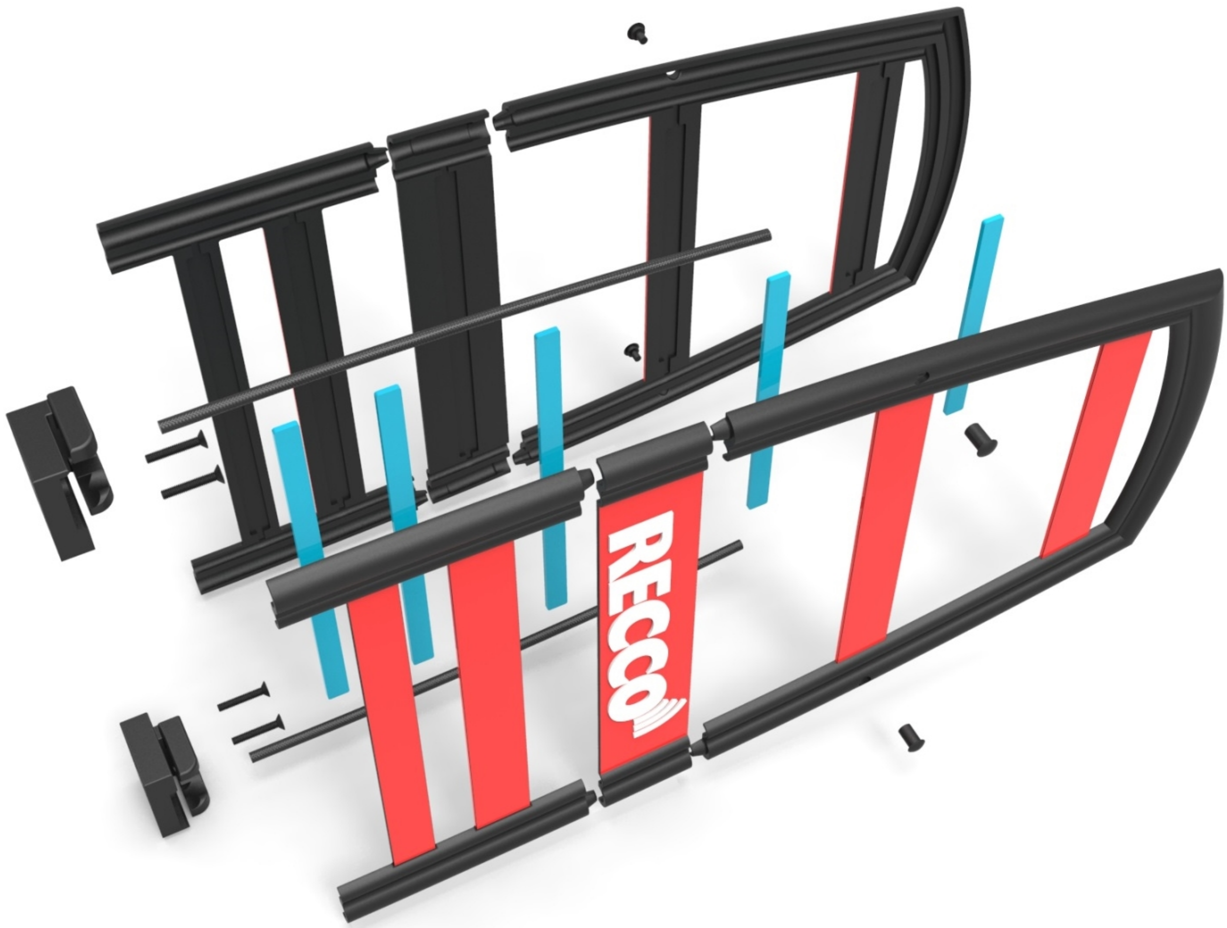

Figure 33. *The antenna in exploded view, the blue parts in the middle are the directors.*

The antenna will be produced out of black PC, the red and white colour will come from in mould decoration (IMD). In mould decoration is more environmentally friendly than painting or spraying, which emit volatile organic compounds (VOCs) (Lefteri, 2012). However, IMD is a more expensive than other methods like tampon-print, but has much higher quality on black backgrounds. Presenting different rendered colour options, RECCO decided which colour they thought suited the antenna best. In the end RECCO choose red, which are meant to associate to both the company's own logo colours and to rescue equipment which often is red in western countries (Granhed, et al., 2014). Red is perceived to be a warning light colour, provokes a sense of alarm and has a high contrast to the white surroundings in winter conditions which is important for visibility. (Osvalder & Ulfvengren, 2008)

Assembling

With the parts created they need to be assembled. The assembling consists of placing the directors, bonding the similar parts and tread through the rubber cord in the antenna parts to tie them together.

The directors will be made out of thin aluminium tape to ease the assembling and lower the weight. This is a decision made by RECCO (Granhed, et al., 2014).

There are a couple of methods to choose from when it comes to joining the plastic antenna parts. Since Mälarplast most likely will be the manufacturer they had to be able to produce the joining method. The methods that Mälarplast can produce are snap fits, friction welding and gluing. Gluing is eliminated though since it is too time consuming and too expensive (Bruder, 2011).

The choice is then between snap fits and friction joining. Snap fits would be “built into” the parts so that they just have to be pressed together. The problem with snap fits is that there are no room to fit them and make them feasible for manufacturing. Left is only the joining method friction welding.

Friction welding can be done in a couple of different ways and the one that would be used by Mälarplast for this product would be vibration welding. With vibration welding the weld seam on the product can be both leak proof and invisible from the outside. With a leak proof weld seam there is no risk for the directors to corrode. To be able to weld the pieces together with friction welding the pieces needs to be able to move about 1.8 mm relatively to each other, which they are designed to do. To get an invisible weld seam a pocket is added, see Figure 34, which catches the excess material. For this piece the weld height, *h,* is set to 0.5 mm and β is 60° since it is an amorphous plastic and relatively big pieces. (Plastforum, 2006)

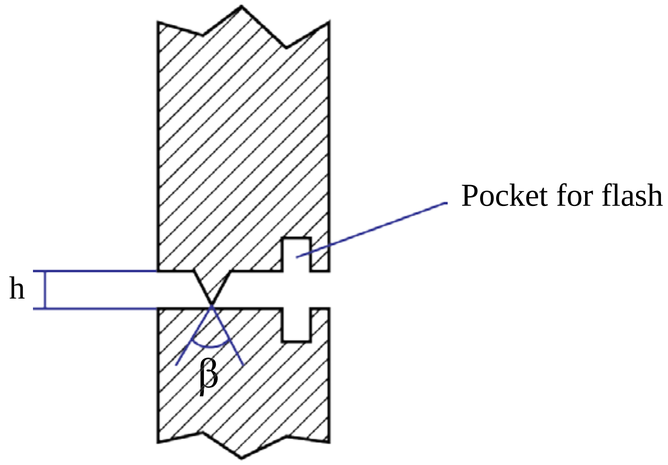

Figure 34. *An illustration over the weld seam with “h” as the height of the weld.*

When the antenna pieces are welded they need to be connected with the rubber cord. The cord will be thread through the pieces and fixed by hand. At the tip of the antenna the rubber cord is connected to a plug that holds it in place. To secure the rubber cord in the base module a mounting system was designed and combined in the snap fit design. On the back of the snap fit a tight fixture with teeth holds the cord in position when mounted, see Figure 35. This enables the user to tighten the rubber cord if it gets worn out and or too loose.

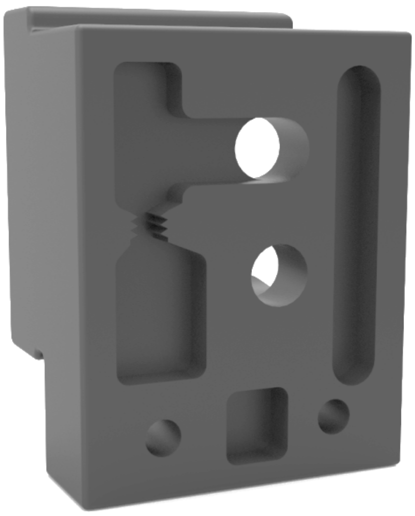

Figure 35. *Rubber cord mounting system, the cord enters at the upper hole and then folds to the left and down.*

5.4. *Weight and Stress calculation*

To make sure that the antenna meets the requirements in terms of weight and durability the dimensions of the antenna have been established by calculations both by hand and in different computer programs. These calculations are presented in the following chapter.

Weight

The total weight for the antenna, snap fit, plugs, screws, rubber cord and the directors is 188,6 gram, see Table 1. The calculations have been made in SolidWorks (Dassault Systemes, 2013) with the assigned materials. The weight is almost 3 times higher than the R9 model where the antenna had a total weight of 65 gram. However, the antenna has doubled in length, been provided with more directors and improved mechanical protection.

Table 1. *All the parts with their assigned material, weight and number of parts.*

Part	Material	Weight	# of parts	Total Weight
Inner antenna	PC	17,3 g	2	34,6 g
Middle antenna	PC	13,4 g	2	26,8 g
Outer antenna	PC	37,6 g	2	75,2 g
Snap fit	POM	14,7 g	2	29,4 g
Plug	PC	0,8 g	2	1,6 g
Screw	POM	0,15 g	4	0,6 g
Rubber cord	Latex	7,8 g	2	15,4 g
Director	Aluminium	1 g	5	5 g
				188,6 g

Snap fit

To ensure the durability of the snap fits when exposed to hard winds from helicopters and rough weather conditions calculations were made, see Appendix XI. Forces from cases of wind gusts were calculated, assuming wind speeds up to 28 m/s coming from the side and a fix antenna. In consequence the resulting momentum of 2,75 Nm is absorbed by two snap fits, which means that every snap fit must at least withhold 1,38 Nm. This lead to a redesigning process of the snap fits from the first concept versions. The arms became wider and the new cross section dimension is 7x7 mm at the base. FEM-calculations were made to confirm that the design will tolerate stresses from 2 mm displacement when the antenna is pushed into the snap fit, see Appendix XII. The mating force in room temperature was calculated to 229,7 N, and in cold weather (-30°C) the same mating force increased by 43% to 330,1 N. The reason for this is that the materials tensile modulus increases with lower temperature.

Rubber cord

Calculations were made to state which rubber cord to choose to keep the antenna from folding as a consequence of strong winds. According to the calculations in Appendix XI – Calculations a rubber cord will need to produce 22,5 N. A rubber cord with 4 mm in diameter was chosen; it has an elongation of 150% and is UV-protected to last longer. The breaking load is at 70 kg or about 670 N.

5.5. *Mould flow analysis*

To ensure the feasibility in terms of manufacturing with injection moulding the program Autodesk Inventor Professional (Autodesk, 2013) was used to do mould flow analysis.

First, the antenna was analysed. Gate locations were determined, runners were placed and the sprue bushing positioned. Next the program calculated the process settings. Mould temperature was 105 °C, melt temperature 319°C and the necessary injection pressure set to 1800 bar.

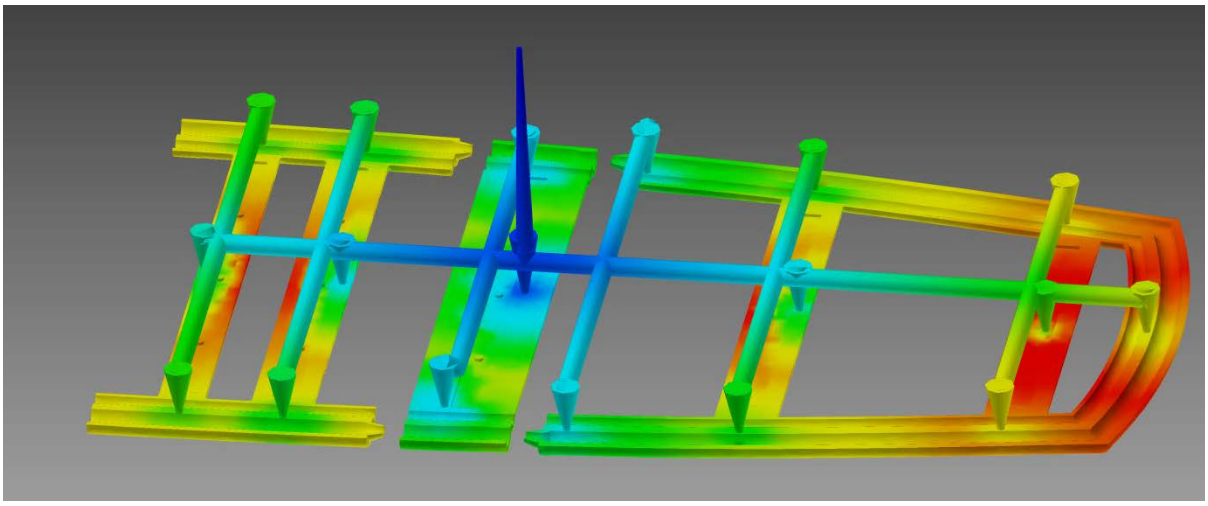

Figure 36 *Filling time for the antenna parts is 1,1 s.*

The filling time was calculated to 1,1 s and the total cycle time to 44,2 s, see Figure 36. This high increase in time length is due to the needed cooling time accordingly to the chosen material and thickness. With cooling canals installed the total cycle time would decrease significantly. The confidence of fill was calculated to 74% high and 26% medium, see Figure 37.

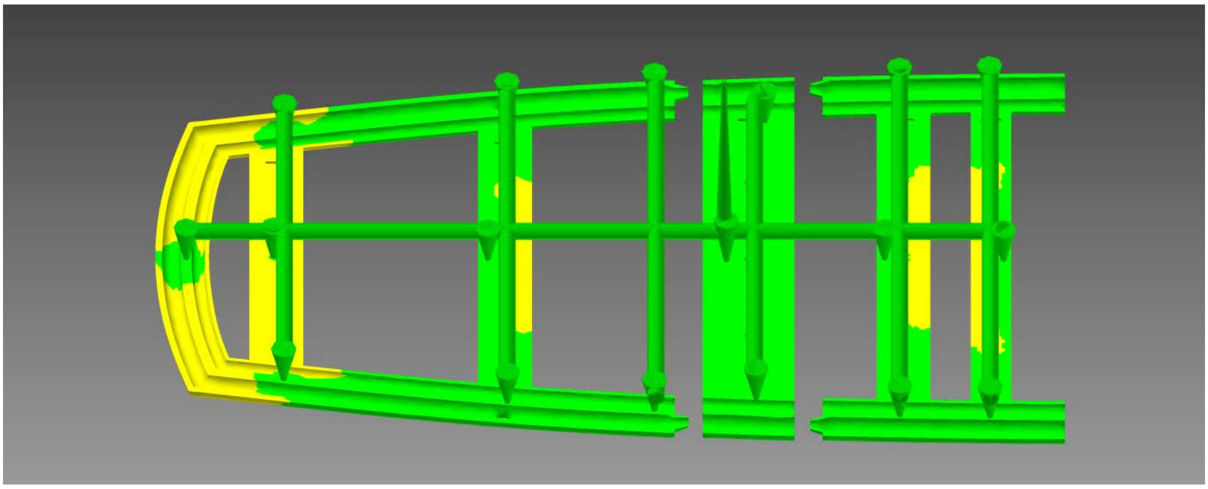

Figure 37 *Confidence of fill, yellow 26% (medium), green 74% (high).*

The reason why all three antenna parts are connected with runners is so that they can be made with only one mould tool. This so called multi cavity tool leads to the reduction from three tools to one, which lowers the total tool costs significantly.

For the snap fit the same multi cavity method can be selected since both snap fits are mirrored and consists of the same material. Therefore, one upper snap fit and one lower snap fit were gathered and connected with runners, see Figure 38. For higher efficiency these snap fit can be assembled in patterns in the multi cavity tool to get even more parts with every cycle. The design has cavities from more than two directions and therefor cavity slides will be needed.

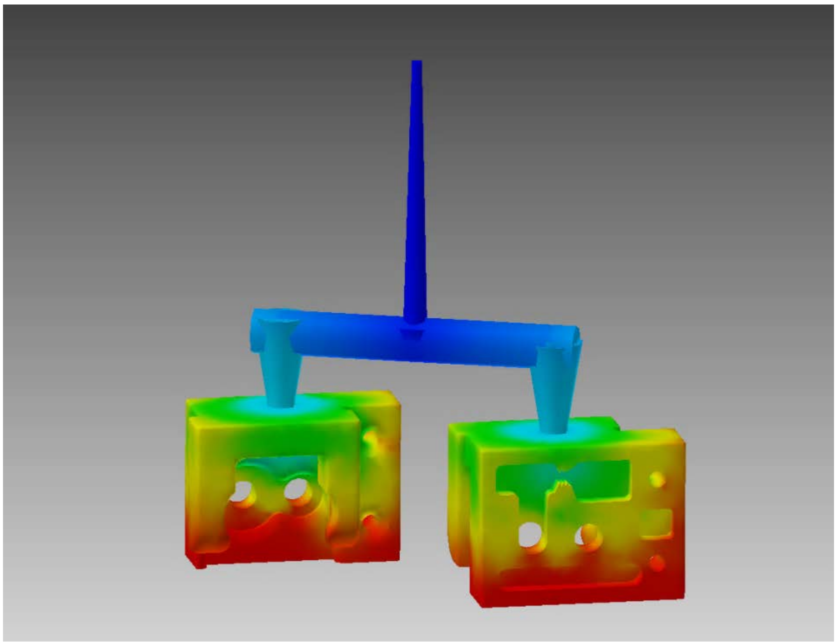

Figure 38 *Filling time for the snap fits 8,64 s.*

Mould temperature was 91°C, melt temperature 201°C and the necessary injection pressure was set to 1800 bar. The filling time was calculated to 8,6 s and the total cycle time to 248,8 s.

This high increase in time is due to the material, which cools down very slowly. On the other hand slower filling time increases the confidence of fill. With cooling canals installed the total cycle time would decrease significantly. In the case of the snap fits the confidence of fill is calculated to 100% high, see Figure 39.

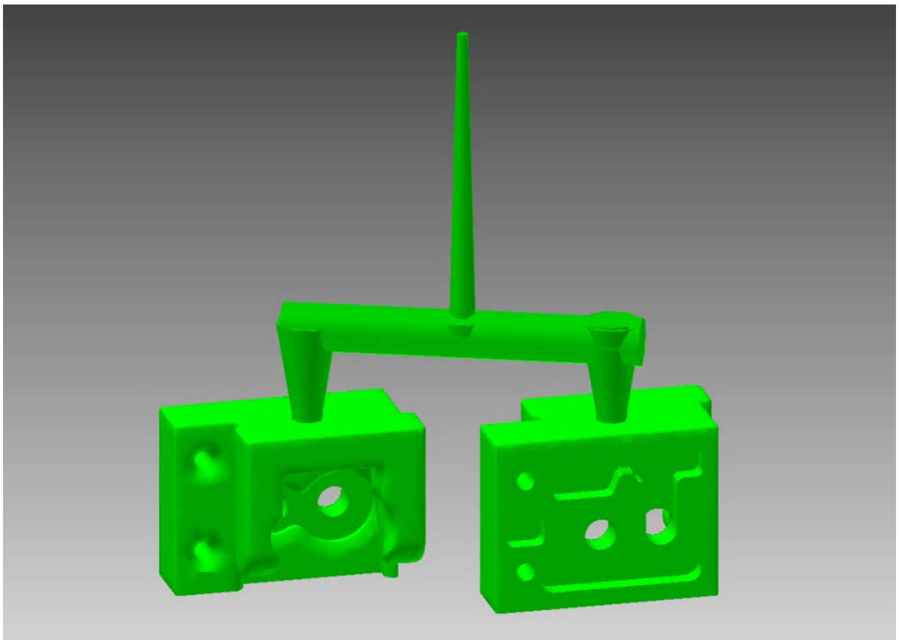

Figure 39 *Confidence of fill for the snap fits, 100% high.*

5.6. *Final prototypes*

To confirm the design changes and evaluate the whole detector with the antenna a new complete prototype was made; see Figure 40 or for technical drawings see Appendix XIII. The antenna and snap fits where ordered from the rapid prototype making company ACRON and were made in a Selective laser sintering (SLS) machine. The body of the detector was made by the authors in chemical wood and milled in a CNC-milling machine while the blue handle was made in a fused deposition modelling (FDM) machine with ABS material.

Figure 40. *The final prototype of the antenna in extended position.*

The prototype is made to test the antenna design in both folded and in extended position. As seen in Figure 41 the antenna has a rubber band to hold it together in folded position. This was made since it was not possible to mill a resting pocket for the antenna. Even without the pocket for the antenna the folded position could be tested and confirmed to work as planned.

Figure 41. *The prototype of the antenna in folded position.*

To see how the antenna parts would feel when coming out of the injection moulding machine, and to communicate the idea of the manufacturing process, six prototypes of the divided antenna parts were made. The parts, which can be seen in Figure 42, were made in a powder 3D-printing machine. As seen on the parts there are some minor changes done to the finished design after these prototypes were made; the small spikes where the directors are to be placed are removed, and the canals from the cavity for the directors to the inner canal is made.

Figure 42. *The antenna parts as they will look like before assembling.*

6. Discussion and conclusion

In this chapter a discussion regarding the methodology and result of the master thesis is presented along with connections to the methods used. The conclusions are based on the discussion and the result and intend to answer whether the purpose of the master thesis has been fulfilled or not.

6.1. *Discussion of methodology*

Information gathering has been a big and important role in this master thesis. Since most of the information and knowledge have existed within RECCO and their employees a lot of interviews were done. This was mostly done according to Osvalder's (2008) semi-structured interviews and it was confirmed, as stated by Osvalder, that this is one of the most fundamental forms of information retrieval. Problems with the interviews are that they are time consuming and sometimes the interviewees have been hard to book. All interviews are time consuming and to retrieve the information in any other way would have been hard since it only exist in the minds of the employees. The problem with booking the interviews could have been solved with earlier planning but also this would have been difficult since it was unclear from the beginning when the interviews needed to take place.

A large amount of time was spent on defining the projects requirements and both two specifications of requirements and a QFD were done. As Alexander and Beus-Dukic (2009) states a project without defined requirements cannot anticipate what needs to be done and the extent of the work. The amount of time spent on the requirements was really valuable during the rest of the project; from brainstorming and evaluation of concepts to construction and validating the final results.

The prototypes have played as a major role in this master thesis. The prototypes provided a feeling for the future product so that improvements have been discovered that could not be seen on a CAD-model. As Kaulio (1998) mentions it is important that the concepts are realistically and understandably explained to enable proper feedback from the client and user.

The prototype feedback from the client essentially helped the project in the right way. This happened in an iterative way with numerous meetings following Kaulio's (1998) main interfaces for customer involvement, which are specification, concept development and prototyping. The feedback from RECCO in these meetings was of great importance for the project and without the clients involvement the same result would never been achieved.

Even though the material selection method showed that PC, used in the old antenna, is the most suitable material for the antenna, the method was a great confirmation of this. It was also confirmed from three sources; Bruder (2014), Mälarplast (2014) and CES EduPack (2013) that POM was the most suitable material for the snap fit. It was discovered that along the way of using the knowledge from the company; RECCO (2014), manufacturer; Mälarplast (2014) and material specialist; Ulf Bruder (2014) a lot of construction feedback was given which was not the purpose but very appreciated.

6.2. *Discussion of results*

The goal with this master thesis was: "by the use of a sufficient development process; improve and develop RECCO's R9 antenna by increasing its length to give it a better search performance, but still keep it practical and robust, as well as making it production ready".

A new antenna and mounting system have been developed that are twice the length of the R9's antenna and that are proven practical with prototypes and theoretically robust. However, whether the antenna has a better search performance, is practical and robust have not yet been scientifically proven. To evaluate this, a fully functional prototype would need to be produced and tested with the new R10 design.

The final design has not yet been established since the size and placement of the directors are not decided. RECCO is working on the design of the housing for the R10 detector and when that is done the antenna design has to be changed to fit the new directives. The construction is designed in a universal way, to fit different sizes of directors without affecting the structure.

The total weight of the new antenna is calculated to 189 gram. This is almost 3 times more than the R9 model. The ergonomic requirement says that the antenna should be *light weight* and defines this as less than 200 gram. This number comes from discussions with RECCO and with lighter components inside the detector the total weight on the detector will be less than R9's weight.

The fitting between the antenna parts still needs some fine tuning and to be tested with a more similar material as the end product will have. It is hard to evaluate the prototypes that are made in 3D-printers since especially the friction and durability between these differ from the end product.

6.3. *Conclusions*

- The amount of time spent on the requirements was greatly valuable during the rest of the project due to its limits and goals.
- Prototypes are an efficient method to realistically and understandably explain an idea or a concept, and to get proper feedback from a client.
- The material selection method is not only useful for material selection; the experts contacted can also give valuable feedback on the construction.
- It is hard to find any other solution than a rubber band system that can cope with the demands that the antenna has to be steady enough to cope with strong winds, withstand a fall and hold together the pieces after releasing.
- The final design can not be implemented until RECCO has decided the exact size and position for the directors as well as the design of the R10 housing.

7. Recommendations and future work

Recommendations for further development and future work are presented in this chapter.

7.1. *Recommendations*

A general recommendation for future development of RECCO products is to use and improve the specification of requirements that this project designed. This would help to anticipate what needs to be done and the extent of that work as well as keeping the company constantly improving their work by setting new goals.

At the final presentation for RECCO, it came to knowledge that a single centred antenna may not be as good as intended. The antenna group discovered that the antenna appears to produce an area of radio shadow in the forward lobe along the centre line. This is alarming since the desired accuracy is along the centre line. Therefor it is absolutely necessary to perform more tests with the centred antenna to eliminate any doubts of accuracy before doing any further work on the antenna.

7.2. *Future work*

Before more work is put into the antenna the placement and size of the directors should be decided. Furthermore the detector needs to be integrated with the design of the antenna since they are depending on each other. It could be so that minor changes needs to be done where the two are connected, such as on the snap fits or where the antenna is placed when folded.

The next step is to manufacture prototypes more similar to the end product to test before expensive injection moulds are produced. This can be done in silicon moulds that are significantly cheaper than steel moulds. Even though a silicone mould only can produce about 10 pieces before it gets worn out it is enough for the test parts that can confirm the design (Bruder, 2011).

With the silicon mould parts, tests and validations can be performed on the antenna. People who normally use it, i.e. rescue workers, should test the antenna in as real life conditions as possible. After testing there should be an evaluation and validation of the design and performance. This will show if the antenna is production ready or if any redesigning is necessary.

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Appendix I – RECCO's requirements

In this appendix the first specification of requirements for the antenna, made together with RECCO, is presented.

Version 1.0

March 17, 2014

Project goal

The goal is to develop and evaluate the antenna of RECCO's detector R9 to give it a better search performance and still keep it robust and easy to use.

Time frame

The project takes place during 20 weeks from February until June 2014.

Requirements

The antenna must..

.. have the length to fit 5 directors.

.. have as good signal as the R8 detector.

.. be as small as the R9 antenna when not in use.

.. be placed in the middle of the detector.

.. withstand a fall.

.. be easy to reposition after a fall.

.. stay attached to the detector after a fall.

.. be able to fit different sized directors.

.. withstand down force from a helicopter.

.. be easy to extend.

.. be light weight.

.. withstand temperature differences.

.. be water resistance.

.. not have any metal against metal in it.

The antenna should..

.. be cheap to produce.

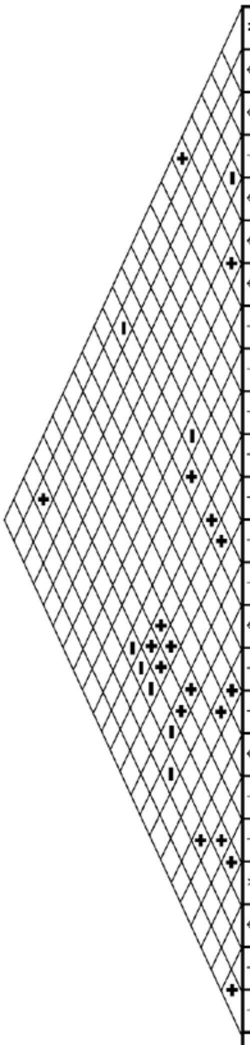
.. have an environmentally friendly production.

.. be made of environmentally friendly material.

.. feel robust.

In this appendix the Quality Function Deployment house is presented.

■ = 9
▲ = 3
O = 1



Customer needs			Priority	Steps to extend	Time to extend	Force to break/fold/release	Rubber cord	Steps to reposition	Time to reposition	Wind force to break/fold	Weight	Size	Force to open	Manufacturing cost / unit	Material cost / unit	Steps to assemble	Time to assemble	Parts to assemble	Energy / unit	CO^2 footprint	Gain	Numbers of directors	Max. temperature	Min. temperature	Durability water	Survey about feeling	Metal against metal?	Now 1 (1 = Very bad)	Now 2	Now 3	Now 4	Now 5 (5 = Very good)
Goal				↓	↓	↑	Y	↓	↓	↑	↓	↓	↑	↓	↓	↓	↓	↓	↓	↓	↑	↑	↑	↓	↑	↑	N					□ R9 ● R8
				#	s	N	Y/N	#	s	N	g	dm³	N	kr	kr	#	s	#	Wh	kg/kg	dB	#	C°	C°	1–5	1–5	Y/N	1	2	3	4	5
During rescue search	On foot or skies	Easy to extend	3	■	■								▲																		□	●
		Withstand a fall	9			■					O				▲											O			●			□
		Stay attached to the detector after a fall	9				■																									□●
		Easy repositioning after a fall	9				▲	■	■		▲																			□		●
	From helicopter	Withstand down force	9							■	O																			□	●	
		Light weight	3								■																	□				●
During transportation and storage		Be as small as R9 when it is not in use	9									■																□				●
		Stay in position	3										■																	□		●
Manufacturing		Cheap	3								O			■	■													●		□		
		Easy to assemble	3					▲	▲							■	■	■											●	□		
		Environmentally friendly production	1								O								■	▲									●			□
		Environmentally friendly material	3																▲	■									●			□
Performance		As good signal as R8	9									■									■	■						●				□
		Withstand temperature differences	3																				■	■								●□
		Water resistant	3																						■				●			□
		Feel robust	9								▲															■		●		□		
		No metal against metal	9																								■					●□
		Importance		27	27	81	108	90	90	81	103	162	36	27	54	27	27	27	18	18	81	81	27	27	27	81	81					

Appendix III – Technical specification of requirements

In this appendix a more technical specification of requirements for the antenna is presented.

Version 1.2 | **Priority**

May 20, 2014

3 – Absolutely necessary
2 – Desirable
1 – Small desirability

Nr 1	Communication requirement (expression, identification of the product, describing handling)	Verification method	Goal	Prio. 1-3	Limit
1.1	Feel robust	User test & survey [1-5]	↑	3	4
1.2	Feel expensive, parts fit together nicely	User test & survey [1-5]	↑	2	3
1.3	Perceive as professional	User test & survey [1-5]	↑	2	4
1.4	Signal an easy use	User test & survey [1-5]	↑	1	3

Nr 2	User requirement (Handling, use, functionality, HMI)	Verification method	Goal	Prio. 1-3	Limit
2.1	Easy to extend	Count steps to extend + user survey [# + 1-5]	↓	3	3 + 4
2.2	Easy to fold	Count steps to fold + user survey [# + 1-5]	↓	2	3 + 4
2.3	Easy to reposition after a fall	Count steps to reposition + user survey [# + 1-5]	↓	3	3 + 4

Nr 3	Ergonomic requirement (physical adaptation of the product)	Verification method	Goal	Prio. 1-3	Limit
3.1	Light weight	Measure [g]	↓	1	200
3.2	Be as small as R9 when not in use	Measure [dm^3]	↓	2	N/A
3.3	Not capture the wind to much	Measure [dm^2]	↓	3	N/A

Nr 4	**Technical requirement** (component functions, specifics)	**Verification method**	**Goal**	**Prio. 1-3**	**Limit**
4.1	Withstand down force	Measure force to break/fold [N]	↑	3	17.7
4.2	Withstand a fall	Test [m]	↑	3	1.5
4.3	As good signal as R8	Measure [m]	↑	3	150
4.4	Water resistant	Measure durability [1-5]	↑	1	4
4.5	No metal against metal	[Yes/No]	N	3	Yes
4.6	Handle temperature differences	CES EduPack [C°]	↨	3	-30 – +30
4.7	Fit different sized directors	Test [Yes/No]	Y	3	Yes

Nr 5	**Economic requirement** (production cost, development cost)	**Verification method**	**Goal**	**Prio. 1-3**	**Limit**
5.1	Cheap production cost	Tenders from manufacturers [kr/unit]	↓	2	N/A

Nr 6	**Production requirement** (material, manufacturing, logistic, packing)	**Verification method**	**Goal**	**Prio. 1-3**	**Limit**
6.1	Easy to assemble	Count steps to assemble [#]	↓	1	5
6.2	Injection moulding	[Yes/No]	Y	2	Yes

Nr 7	**Ecological requirement** (environmental, disposal, recycling)	**Verification method**	**Goal**	**Prio. 1-3**	**Limit**
7.1	Environmentally material	CO^2 footprint [kgCO^2/kg]	↓	2	95
7.2	Environmentally production	Embodied energy [MJ/kg]	↓	2	4
7.3	Easy recycling/disposal	User test & survey [1-5]	↓	2	3

In this appendix sketches and ideas from the brainstorming are presented.

The six best concepts from the brainstorming can be seen in Figure 1.

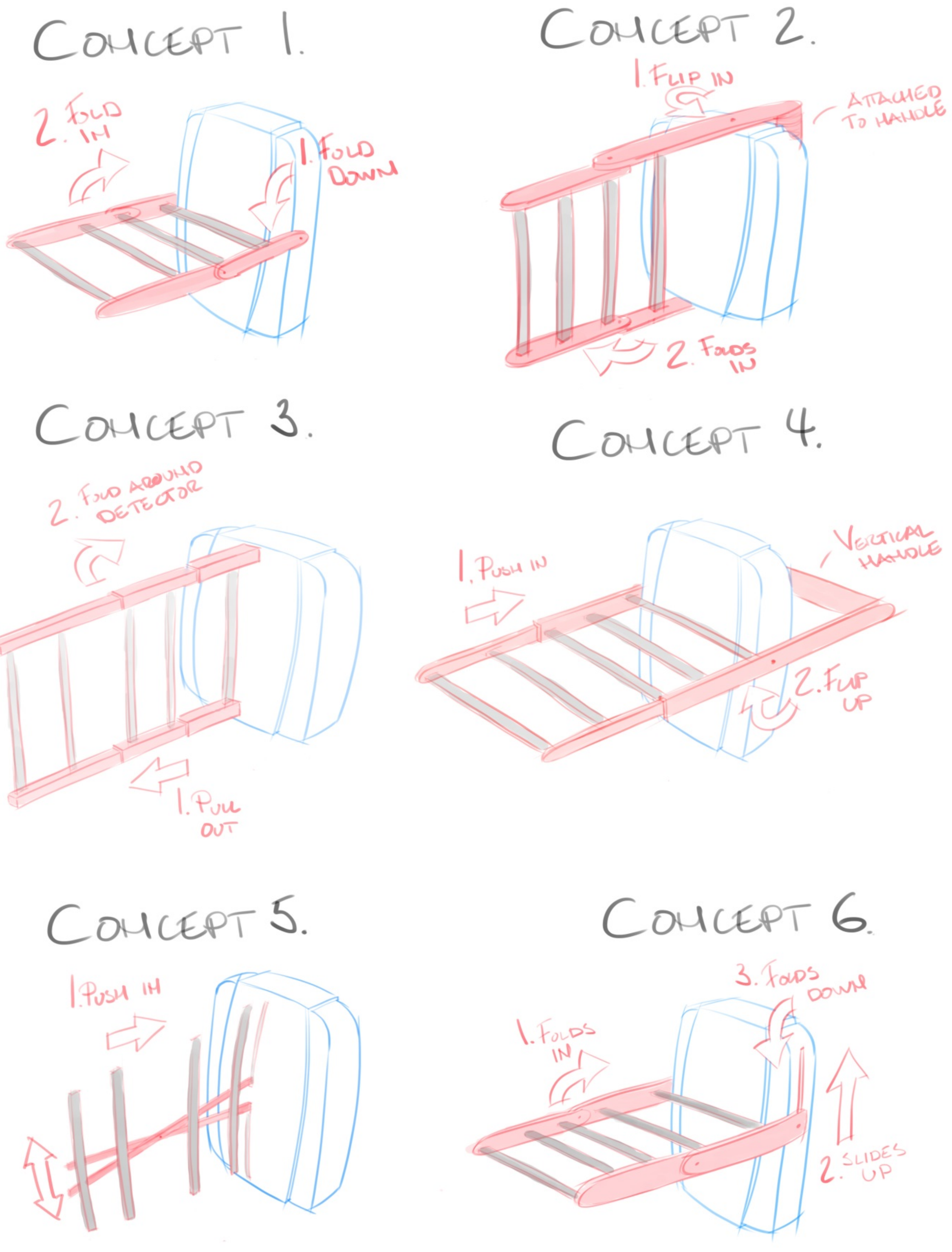


Figure 1. *The six best concepts from the brainstorming.*

One idea was to use the solution that an avalanche probe is using to extend. When the user pulls the handle in Figure 2 the string in the probe will force the different parts together and extend the probe.

Figure 2. *An avalanche probe, the user pulls the handle to tension the rubber band and extend the probe.*

Appendix V – First evaluation of concepts

In this appendix the first evaluation done with Pugh's matrix is presented.

Table 1. *Table of the first evaluation matrix.*

Issue: **Choose concepts to further develop**		**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**	**Concept 6**
Manufacturability	20	Datum	0	-	-	-	-
Robust	10		+	+	+	-	0
Length	20		0	+	0	0	+
Down force	10		+	+	-	+	0
Withstand a fall	20		+	+	-	-	0
Easy to reposition	10		-	?	?	-	0
Easy to extend	10		0	+	0	+	-
	Total		**2**	**4**	**-2**	**-2**	**-1**
	Weighted total		**30**	**50**	**-40**	**-50**	**-10**

In this appendix the 2D-models are presented.

Model 1

Length: 1.5 x detector

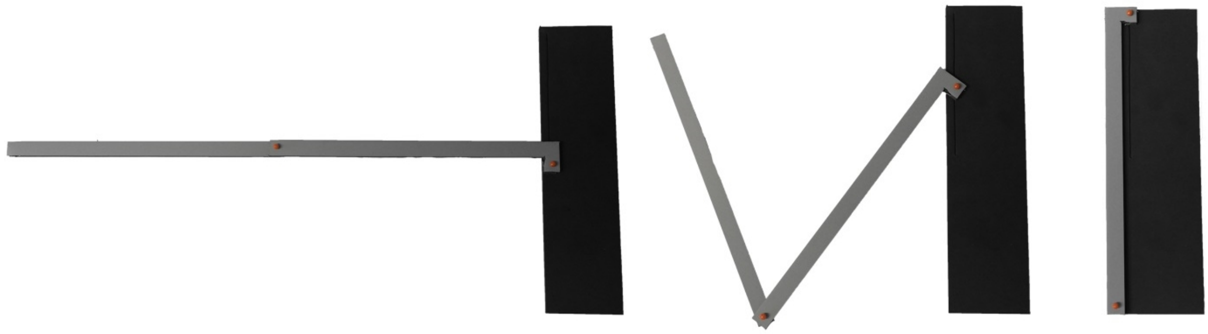
View: Side view or top view

Model 2

Length: 2 x detector

View: Side view or top view

Slides along the side of the detector when folded.

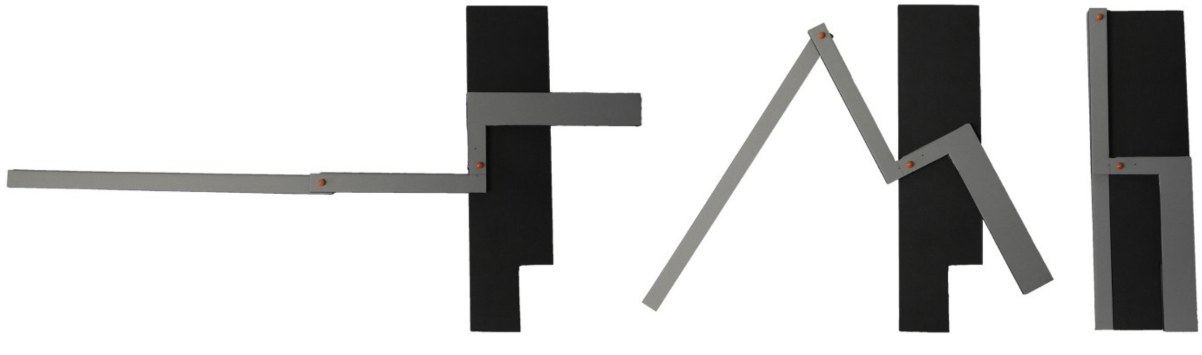


Model 3

Length: 1.5 x detector

View: Top view

Integrated with the handle.

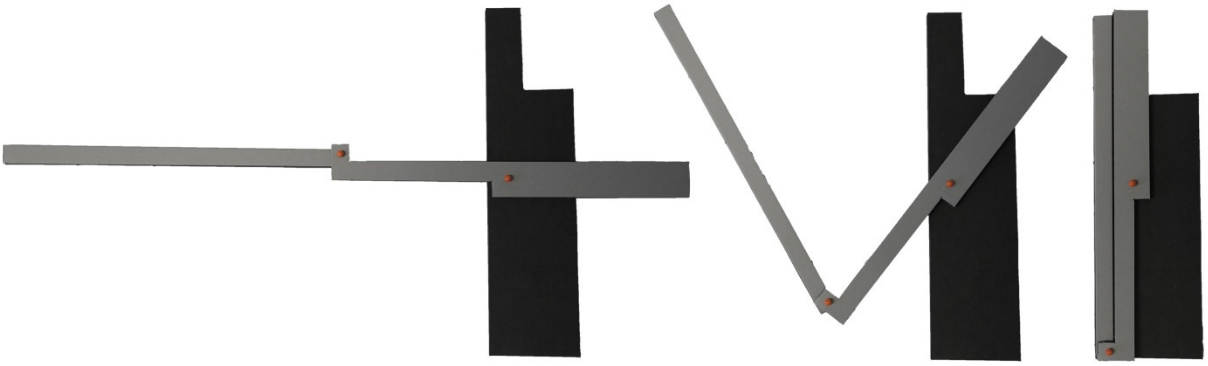


Model 4

Length: 1.5 x detector

View: Top view or side view

Integrated with the handle.

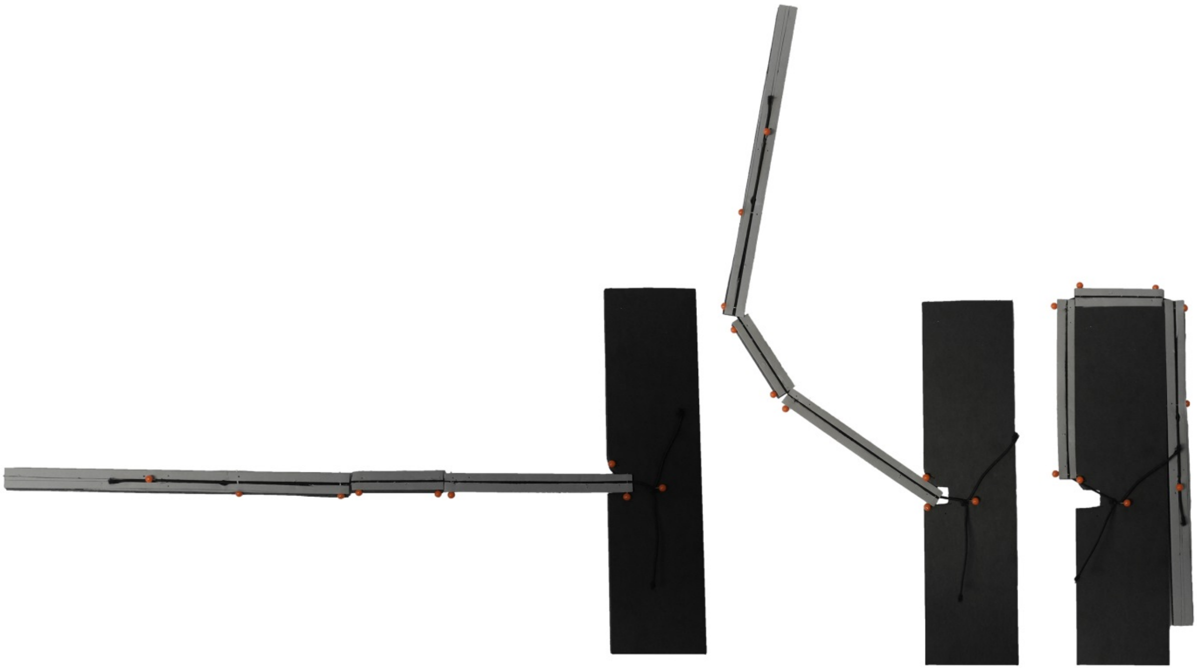


Model 5

Length: 2 x detector

View: Top view

Has a strap that unfolds it and holds it in extended position. When folded it is locked in position with a hook or a snap fit.



Appendix VII – Second evaluation of concepts

In this appendix the second evaluation done with Pugh's matrix is presented.

Table 1. *Table of the second evaluation matrix.*

Issue: **Choose foam model to further develop**		**Model 2**	**Model 1**	**Model 3**	**Model 4**	**Model 5**
Manufacturability	20	Datum	+	0	-	-
Robust	10		0	+	+	0
Length	20		-	-	-	0
Down force	10		-	0	0	0
Withstand a fall	20		0	?	?	+
Easy to reposition	10		0	?	?	+
Easy to extend	10		+	+	+	+
	Total		**0**	**1**	**0**	**2**
	Weighted total		**0**	**0**	**-20**	**20**

In this appendix the prototypes are presented.

The sliding concept

To see if the sliding concept would work at all a function model was made. This model was CNC-milled out of ABS plastic and can be seen in Figure 1 below. The model is in scale 1:1 but consists only of a piece of the detector, the inner antenna and a rubber cord. The prototype showed that it was possible to make a sliding antenna and that the mechanism worked better than assumed. One thing that was noticed was that the "hook" at the top of the sliding track was not necessary. The antenna would stay in its folded position even without it.

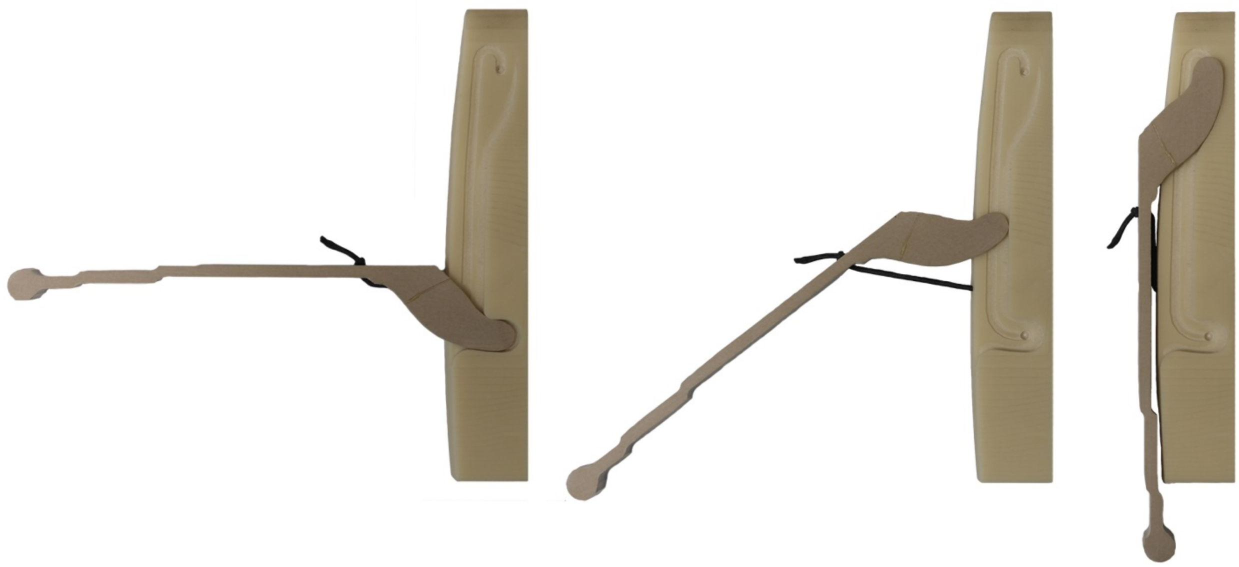


Figure 1. *The sliding concept in profile. The model was a function prototype to try the sliding mechanism.*

A full scale prototype was made of the concept to see how the connection between the antennas would work and how the antenna would handle down force. The model was made out of three different materials and with three different methods. The detector part was made out of chemical wood in a CNC-milling machine, the first antenna part was made in a powder 3D-printer machine using zp130 powder with binder and the outer (blue) antenna part was made in a FDM 3D-printer with ABS material. In Figure 2 the concept can be seen in profile, this shows the thickness of the concept when it is folded.

Figure 2. *The sliding concept folded in profile; the orange on the bottom is the detector then comes the off-white first antenna part and then the blue outer antenna part.*

In Figure 3 the antenna is in its extended position. Here it was discovered that the sliding mechanism worked but the concept was sensitive for pressure on the outer part of the antenna.

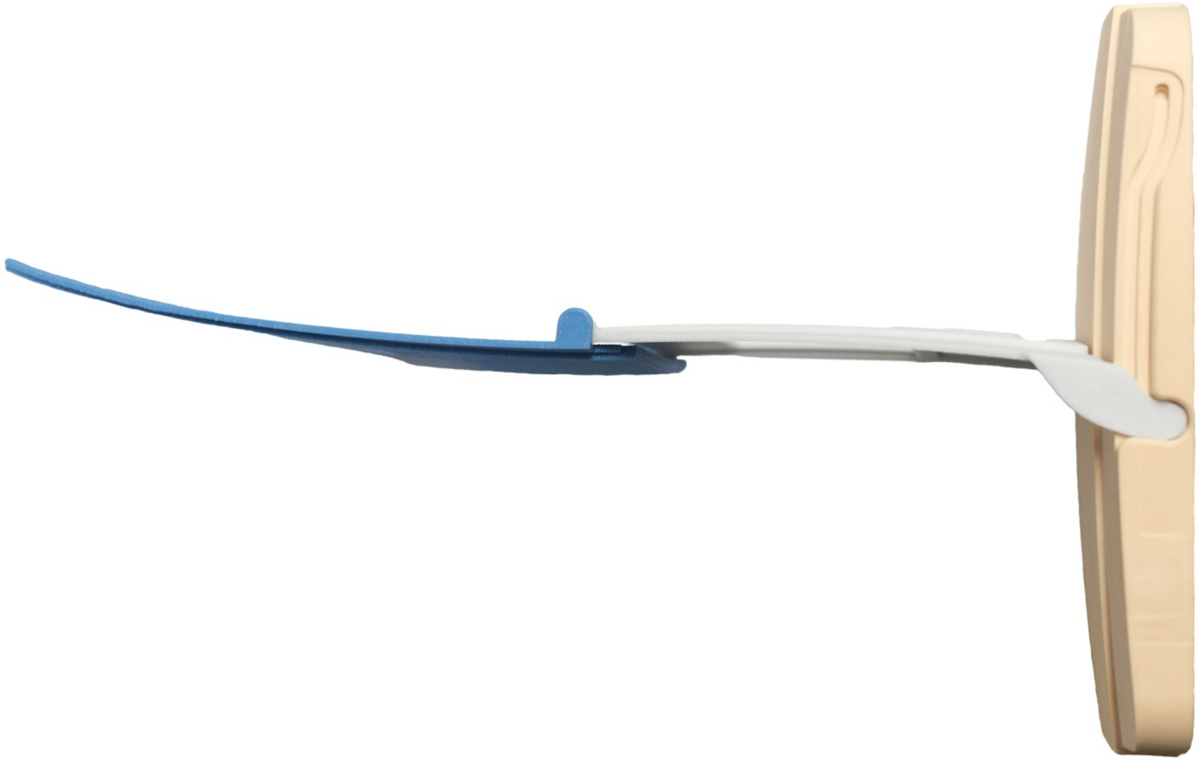


Figure 3. *The sliding concept unfolded in profile; the orange to the left is the detector then comes the off-white first antenna part and then the blue outer antenna part.*

Before a good prototype of the inner antenna was successfully made a lot of broken prototypes came out of the different machines, see Figure 4. This were due to the thin design of the antenna, something that probably would not be a problem when injection moulding the finished design since the injection moulded R9 antenna has a thinner design than the sliding concept's antenna and there are no problems with the R9.

Figure 4. *Different kind of both successful and not so successful prototypes of the antenna.*

The snap fit concept

In the beginning of the prototype making for the snap fit concept a lot of different attachments and snap fits were made to test how the antenna should be connected to the detector. In Figure 5 four initial prototypes were made to test some basic functions. The prototypes to the left and the one in the middle were made to try different depths of the holes for the antenna to be positioned in. The one to the right is a prototype to see the shape of the detector.

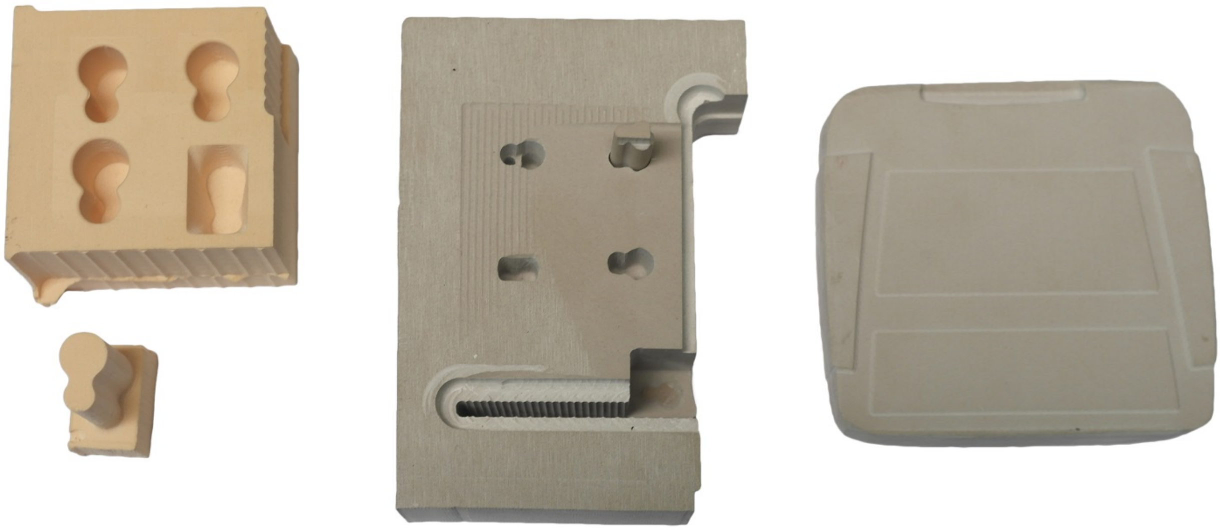


Figure 5. *Four different function prototypes for the snap fit concept.*

To see how the different antenna parts would fit together a full scale prototype was made in a powder 3D-printer, see Figure 6. The powder printer does not give a plastic feel but for this size and shape it was the only option. The prototype showed that the pins that fit the parts together were too long and too big, so that they would not fit together smoothly.

Figure 6. *The snap fit antenna in scale 1:1 with a rubber cord in it.*

One of the most critical parts in the snap fit concept is the snap fit. This has to be strong enough to hold the antenna in place when it is windy but also release if someone would fall on the detector. The snap fit evolution went through a lot steps and Figure 7 shows the different prototypes with the first one to the left and the last one to the right. Things that changed with the design of the snap fit were mostly the thickness of the arms that holds the antenna and the depth of the hole that the antenna slides into.

Figure 7. *The snap fit antenna's snap fits development from left to right.*

Appendix IX – Final evaluation of concepts

In this appendix the final evaluation done with Pugh's matrix is presented.

Table 1. *Table of the final evaluation matrix.*

Issue: Choose the final concept to further develop		Sliding concept	Snap fit concept
Manufacturability	20	Datum	-
Robust	10		+
Length	20		0
Down force	10		+
Withstand a fall	20		+
Be light weighted	10		0
Cheap to produce	10		-
Be water resistance	10		+
Feel robust	20		+
Easy to reposition	10		+
Easy to extend	10		+
	Total		**5**
	Weighted total		**60**

Appendix X – Material selection

In this appendix the material selection is presented with a table of the input in CES EduPack and the two resulting charts.

Table 1. *Table of the input limits in CES EduPack.*

	Minimum	Maximum	
General properties			
Density		1500	Kg/m^3
Price		32	SEK/kg
Mechanical properties			
Young's modulus	2		GPa
Yield strength	45		MPa
Hardness - Vickers	20		HV
Thermal properties			
Maximum service temp.	40		°C
Minimum service temp.		-40	°C
Electrical properties			
Electrical conductor or insulator	Good insulator		
Processability			
Mouldability	4		1-5
Durability			
Water (fresh & salt)	Excellent		
Material recycling			
Recycle	Yes		Yes/No
Toxicity rating	Non-toxic		

Table 2. *Table of the properties for the three materials. Data from CES EduPack.*

	PC	POM	PMMA	
General properties				
Density	1210	1430	1220	Kg/m^3
Price	30.4	21.7	20.4	SEK/kg
Mechanical properties				
Young's modulus	2.44	5	3.8	GPa
Yield strength	70	72.4	72.4	MPa
Hardness - Vickers	21.7	24.8	21.9	HV
Fracture toughness	4.6	4.2	1.6	$MPa.m^{0.5}$
Thermal properties				
Maximum service temp.	101	76.9	41.9	°C
Minimum service temp.	-73.2	-73.2	-73.2	°C
Electrical properties				
Electrical conductor or insulator	Good	Good	Good	
Processability				
Mouldability	5	5	5	1-5
Durability				
Water (fresh & salt)	Excellent	Excellent	Excellent	
Material recycling				
Recycle	Yes	Yes	Yes	
Toxicity rating	Non-toxic	Non-toxic	Non-toxic	

Appendix XI – Calculations

In this appendix calculation of wind force and snap fits are presented.

Calculations on the snap fit

To ensure that the snap fit will withstand wind gusts while sitting in a helicopter and searching with the antenna outside the helicopter following calculations were made.

Cross section area is measured with SolidWorks to be A = 30900 mm^2 = 0,0309 m^2.

It is assumed that wind gusts while searching can reach υ = 100 km/h = 28m/s.

Further assumptions:	Friction coefficient	C_d = 1,2
	Density of air	ρ_{air} = 1,22 kg/m^3
	Length of beam	L = 0,31m

All formulas are from the book *handbok och formelsamling i hållfasthetslära* (Sundström & M.fl., 2000).

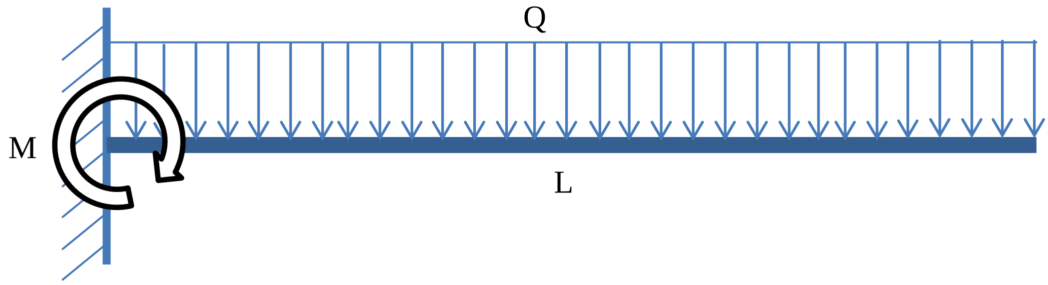


Figure 1. *An illustration over a top view with forces on the antenna.*

$$Q = \frac{1}{2}\rho * \upsilon^2 * A * C_d \quad (1)$$

$$Q = \frac{1}{2} * 1{,}22 * 28^2 * 0{,}0309 * 1{,}2 \quad (2)$$

$$Q = 17{,}73\ N \quad (3)$$

$$M = \frac{QL}{2} \quad (4)$$

$$M = \frac{17{,}73 * 0{,}31}{2} = 2{,}75\ Nm \quad (5)$$

Conclusion: The momentum of 2,75 Nm is absorbed by two snap fits which means that every snap fit must at least withhold 1,38 Nm.

To ensure that the snap fit will withstand 1,38 Nm the necessary mounting force W is calculated. (BASF Corporation, 2007)

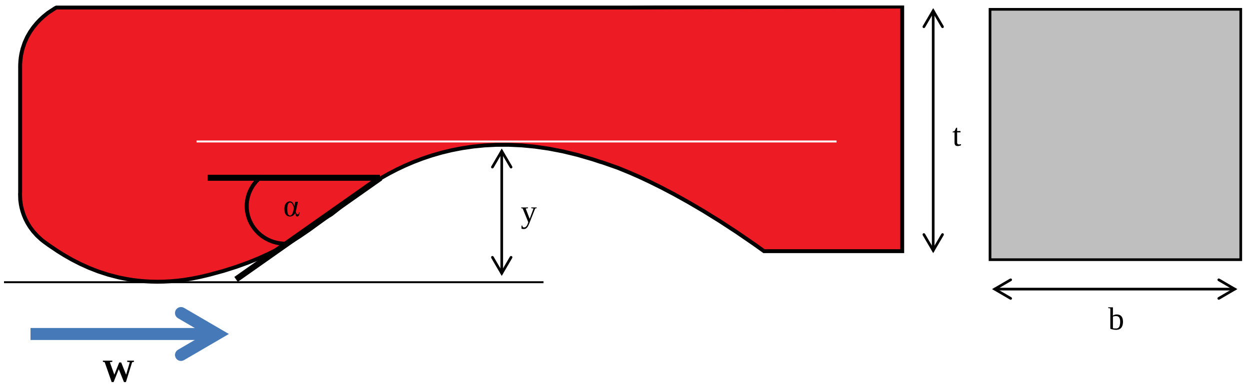


Figure 2. *An illustration over a part section (red) and cross section (grey) with forces on the snap fit.*

Material:	Unfilled Acetal (POM) BASF Ultraform N2320 003		
Assuming:	Displacement Y = 2 mm	E = 2700 MPa (23°C)	L = 18 mm
	A = 15°	t = 7 mm	$\in_0$ = 7%,
	μ = 0,20-0,35	b = 7mm	

$Q\left(\frac{L}{t}=2{,}6\right)=1{,}6$ (From case 3 in Figure IV-1 in *Snap-Fit Design Manual* (BASF Corporation, 2007))

Determine:

a) The maximum deflection of snap
b) The maximum mating force
c) ∈ for Y = 2mm
d) The mating force
e) The mating force at -30° C, E = 3812 MPa

a)

$$\in_0 = 1{,}5\frac{tY_{max}}{L^2Q} \quad Y_{max} = \frac{\in_0 L^2Q}{1{,}5t} \tag{6}$$

$$Q\left(\frac{L}{t}=2{,}6\right)=1{,}6 \tag{7}$$

$$Y_{max} = \frac{(0{,}07)(18^2)(1{,}6)}{1{,}5(7)} = 3{,}46\ mm \tag{8}$$

b) The mating force to perform the maximum deflection of snap:

$$P = \frac{bt^2E \in_0}{6L} \tag{9}$$

$$P = \frac{(7)(7^2)2700(0.07)}{6(18)} = 600.3\ N \tag{10}$$

$$W = P\frac{\mu + tan\alpha}{1-\mu\, tan\alpha} \tag{11}$$

$$W = 600.3 * \frac{0,35 + tan15°}{1 - 0,35 * tan15°} = 409.3\ N \tag{12}$$

$$W_{tot} = 2 * W = 818.6N \tag{13}$$

c)

$$\in = 1,5\frac{tY}{L^2Q} \tag{14}$$

$$\in = 1,5\frac{(7)(2)}{(18^2)(3,3)} = 2\% \tag{15}$$

d)

$$P = \frac{7 * 49 * 2700 * 0.02}{6 * 18} = 168.4\ N \tag{16}$$

$$W = 168.4 * \frac{0,35 + tan15°}{1 - 0,35 * tan15°} = 114.8\ N \tag{17}$$

$$W_{tot}(for\ one\ snapfit) = 2 * W = 229.7N \tag{18}$$

Snap fit centre is located 15 mm off the end of the beam.

$$M = W_{tot} * 0,015 = 229.7 * 0,015 = 3.45\ Nm \tag{19}$$

Conclusion: 1.38 < 3.45 → The snap fit will therefore withstand the possible wind gusts from sitting in a helicopter. The maximum wind speed is 44.4 m/s or 160 km/h.

e)

$$P = \frac{7 * 49 * 3812 * 0.02}{6 * 18} = 242,1\ N \tag{20}$$

$$W = 242,1 * \frac{0,35 + tan15°}{1 - 0,35 * tan15°} = 165,1\ N \tag{21}$$

$$W_{tot}(for\ one\ snapfit) = 2 * W = 330,1N \tag{22}$$

$$M = W_{tot} * 0,015 = 330,1 * 0,015 = 4,95Nm \tag{23}$$

Conclusion: The mounting momentum increases in freezing weather (-30°C) by 43%.

With the material BASF Ultraform N2320 003 (POM) chosen this is confirmed in Figure 3 below. As seen in the graph the tensile modulus is increasing as it gets colder. At room temperature (23°C) it is at 2700 MPa and at -30°C it is already at 3812 MPa, an increase by 41%. This is very close to the calculated 43% increase of momentum needed for assembly in cold condition compared to room temperature.

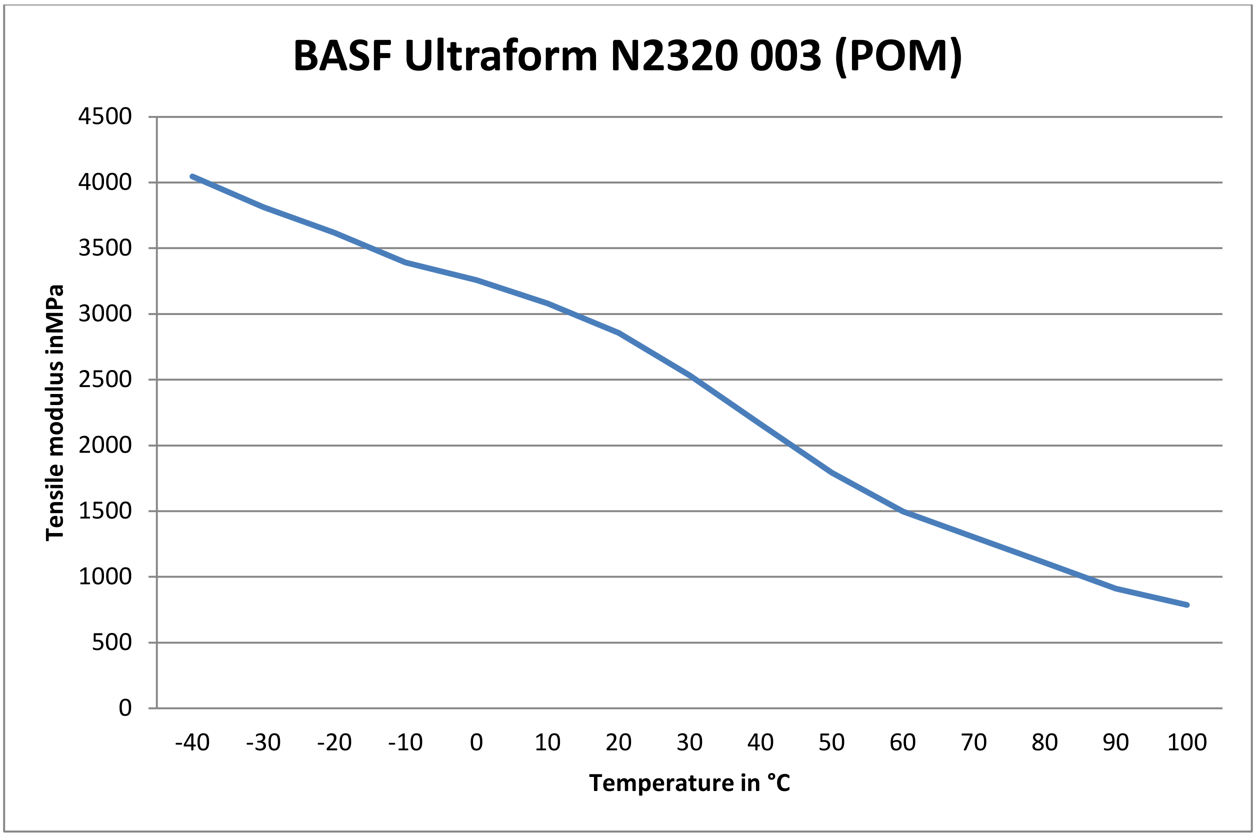
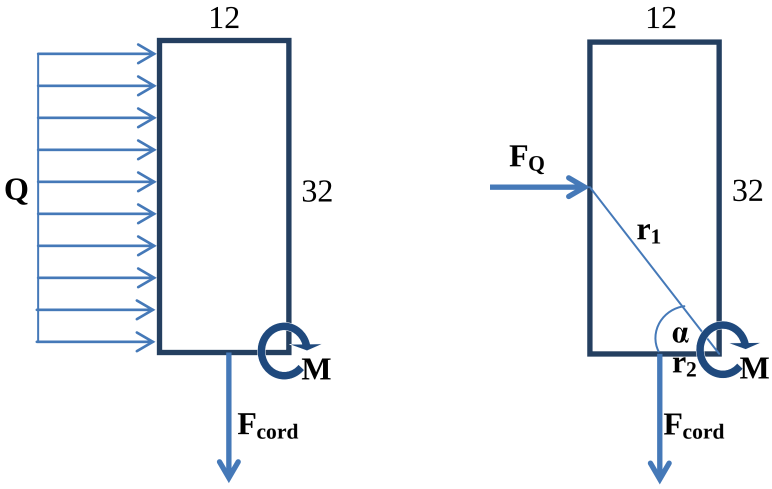


Figure 3. *A graph over how the tensile modulus changes with the temperature* (CAMPUS, 2014).

Calculations on the rubber cord

Evaluation and calculation of forces on rubber cord



Assuming that the distributed load, Q, on the 32 mm wide second antenna-part can be simplified as one force, F_{q}, working in on the center, following applies.

Q=17,73 N

$$r_1 = \sqrt{(\frac{35}{2})^2 + 12^2} = 37mm \tag{24}$$

$r_2 = 6mm$

$\alpha = 55{,}6°$

4

$$M_{wind} = M_{cord} \tag{25}$$

$$F_Q * sin\alpha * r_1 = F_{cord} * r_2 \tag{26}$$

$$\frac{Q}{2} * sin\alpha * r_1 = F_{cord} * r_2 \tag{27}$$

$$F_{cord} = \frac{(17{,}73)(37)\sin(55{,}6)}{2(6)} = 45N \tag{28}$$

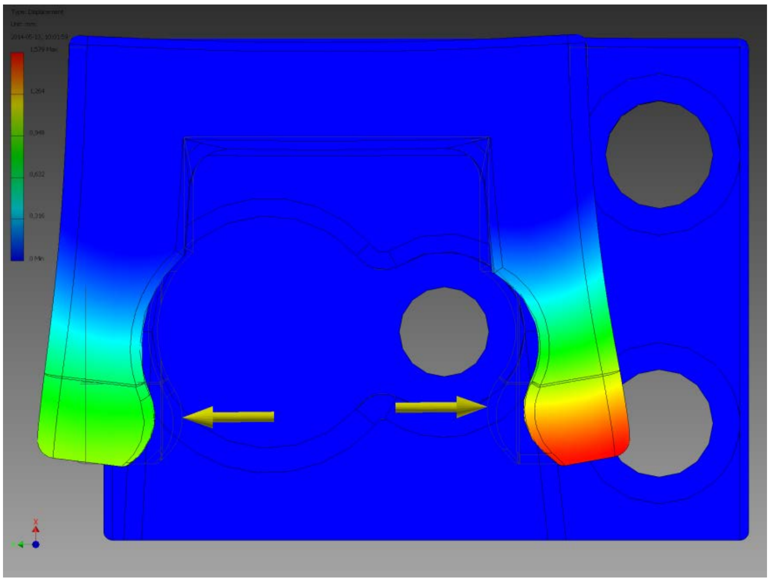
Conclusion: 45 N is the force provided by both sides, therefor one cord will need to produce 22,5 N.

Appendix XII – Validation

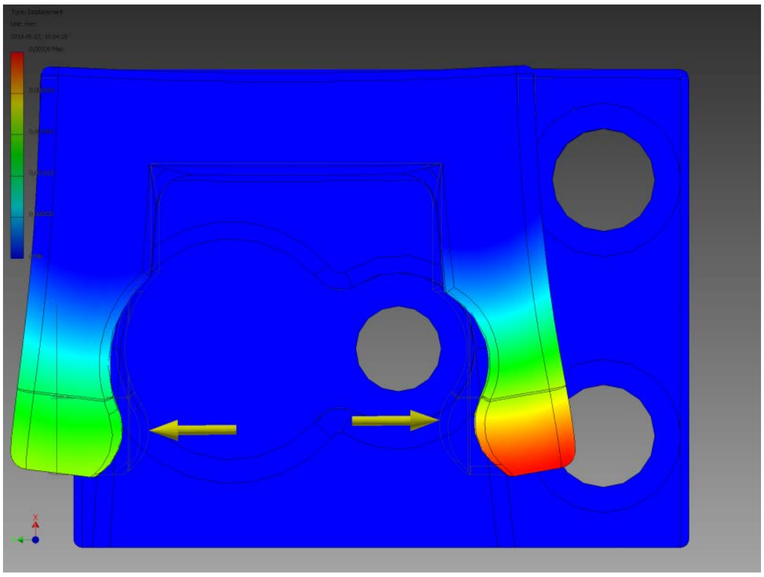
In this appendix validation with finite element methods of forces and snap fits is presented

1. Validation of calculated forces
2. Validation of reaction forces of displacement
3. Validation of stresses for 2 mm displacement

1. FEM for set forces, using forces from the calculations
   Highly red marked areas show the biggest displacement.

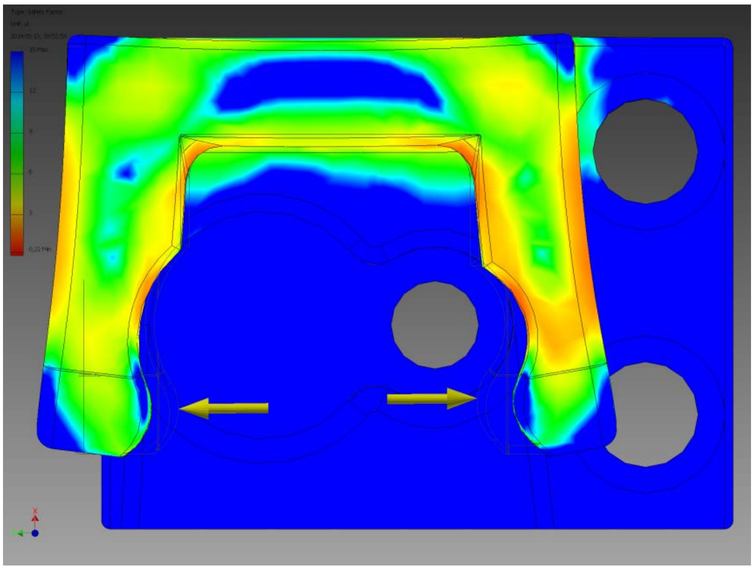


A max. 2.22 mm displacement shown at 23°C resulting from 168.4 N force in both directions.

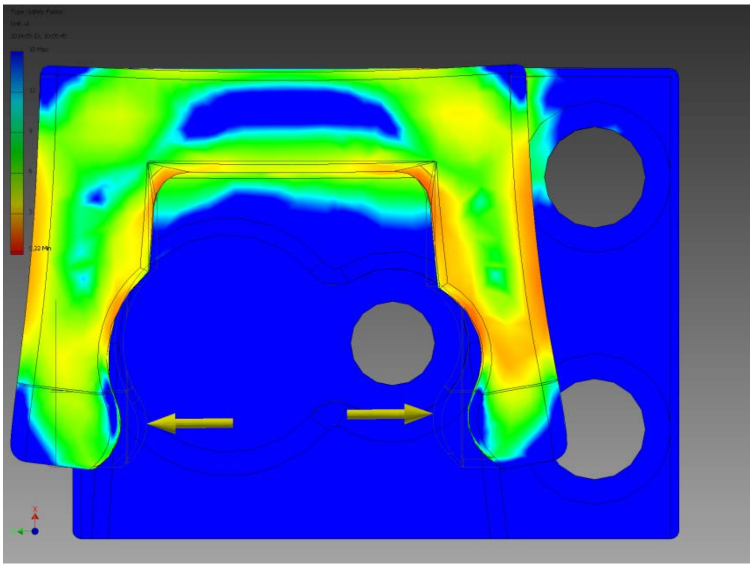


A max. 2.22 mm displacement shown at -30°C resulting from 168.4 N froce in both directions.

Highly red marked areas have low safety factor.



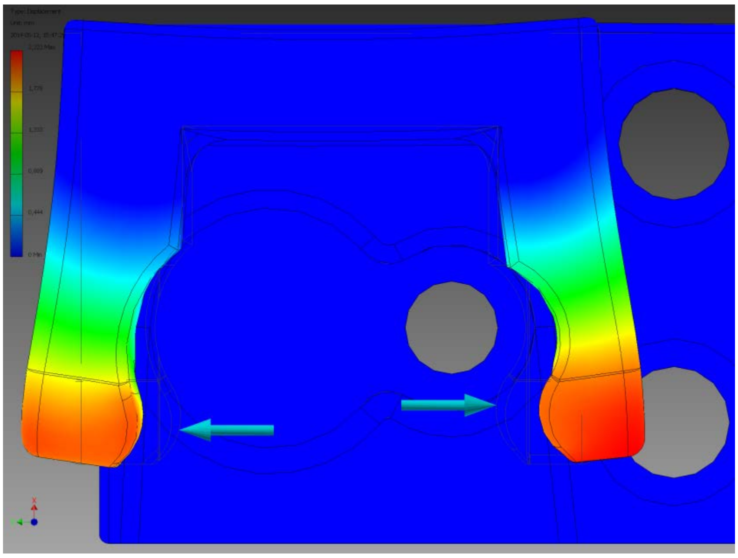
Safety factors at 23°C, minimum 0.22 ul resulting from 168.4 N force in both directions.



Safety factors at -30°C, minimum 0.22 ul resulting from 168.4 N force in both directions.

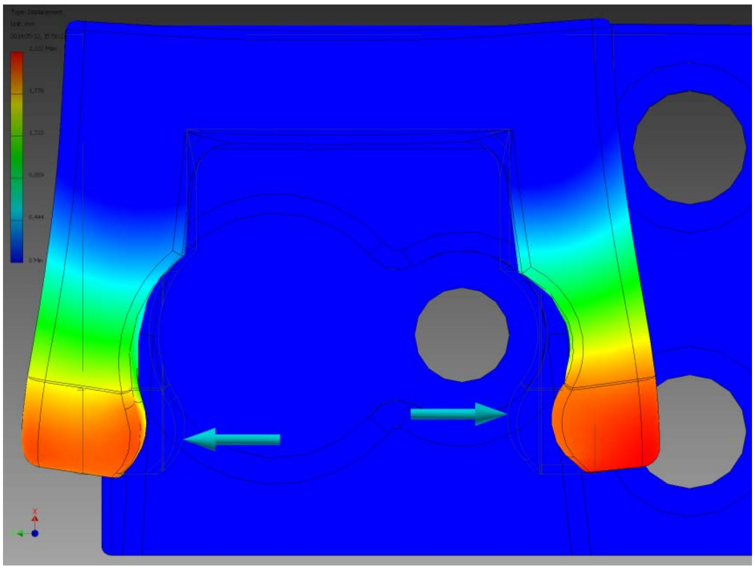
2. FEM for set displacement Y=2mm as it is the displacement the antenna needs for mounting.

Reaction forces are analysed, highly red marked areas have the biggest reaction forces.



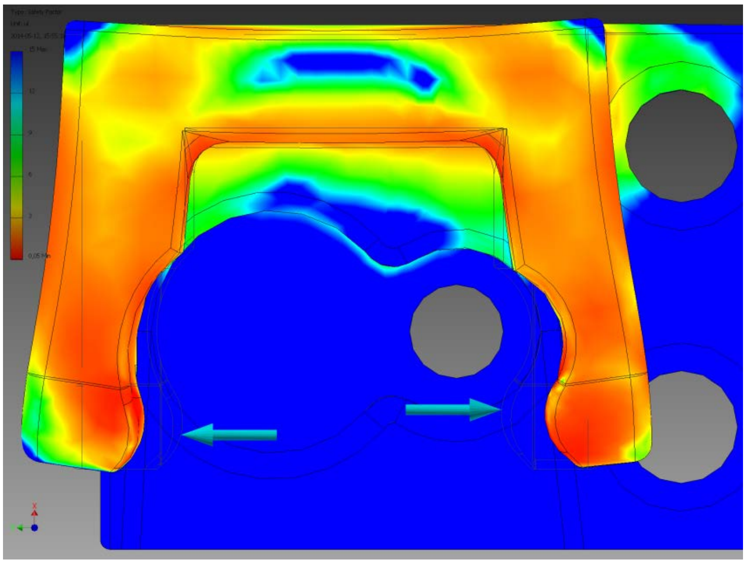
Left reaction force is 379,4 N and right reaction force is 534,2 N at 23°C resulting from 2mm displacement.

The reason for big differences from the calculations and the FEM is due to a strongly simplified model in the manual calculations. On the other hand is the 41 % increase of stress due to the coldness very close to the calculations.

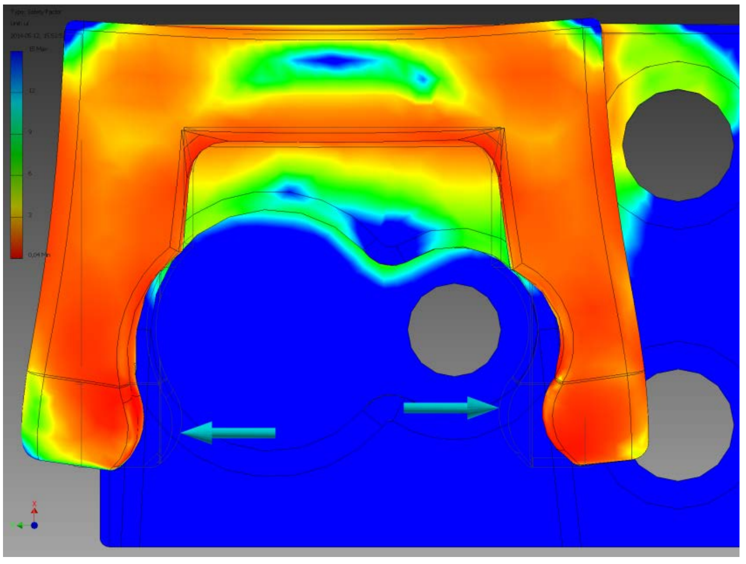


Left reaction force is 535,7 N and right reaction force is 754,3 N at -30°C resulting from 2mm displacement.

3. FEM for stresses for 2 mm displacement



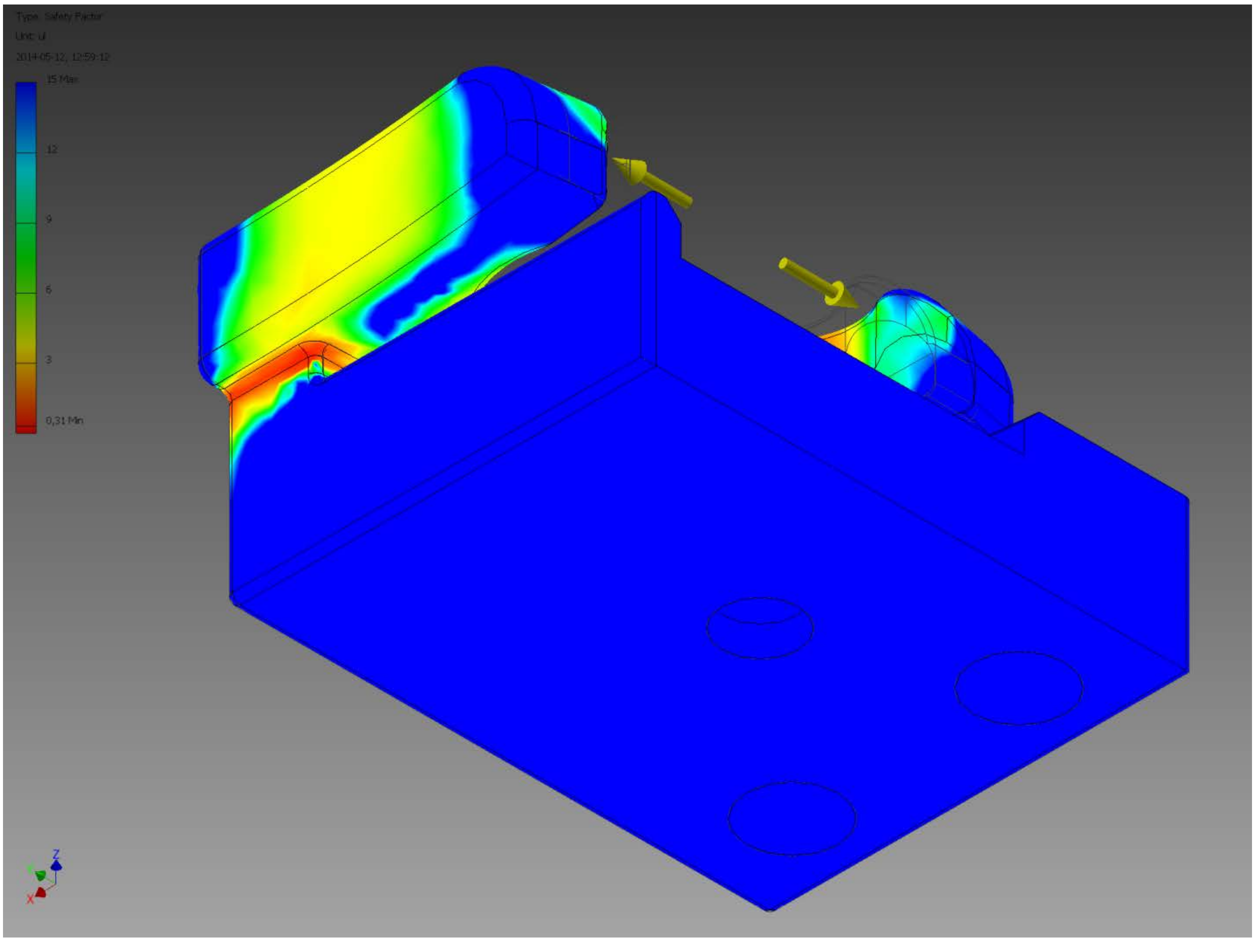
Safety factors at 23°C, minimum 0.05 ul resulting from 2mm displacement on both sides.



Safety factors at -30°C, minimum 0.04 ul resulting from 2mm displacement on both sides.

The safety factor decreases with 25% due to the temperature differences but is still inside an acceptable spectrum.

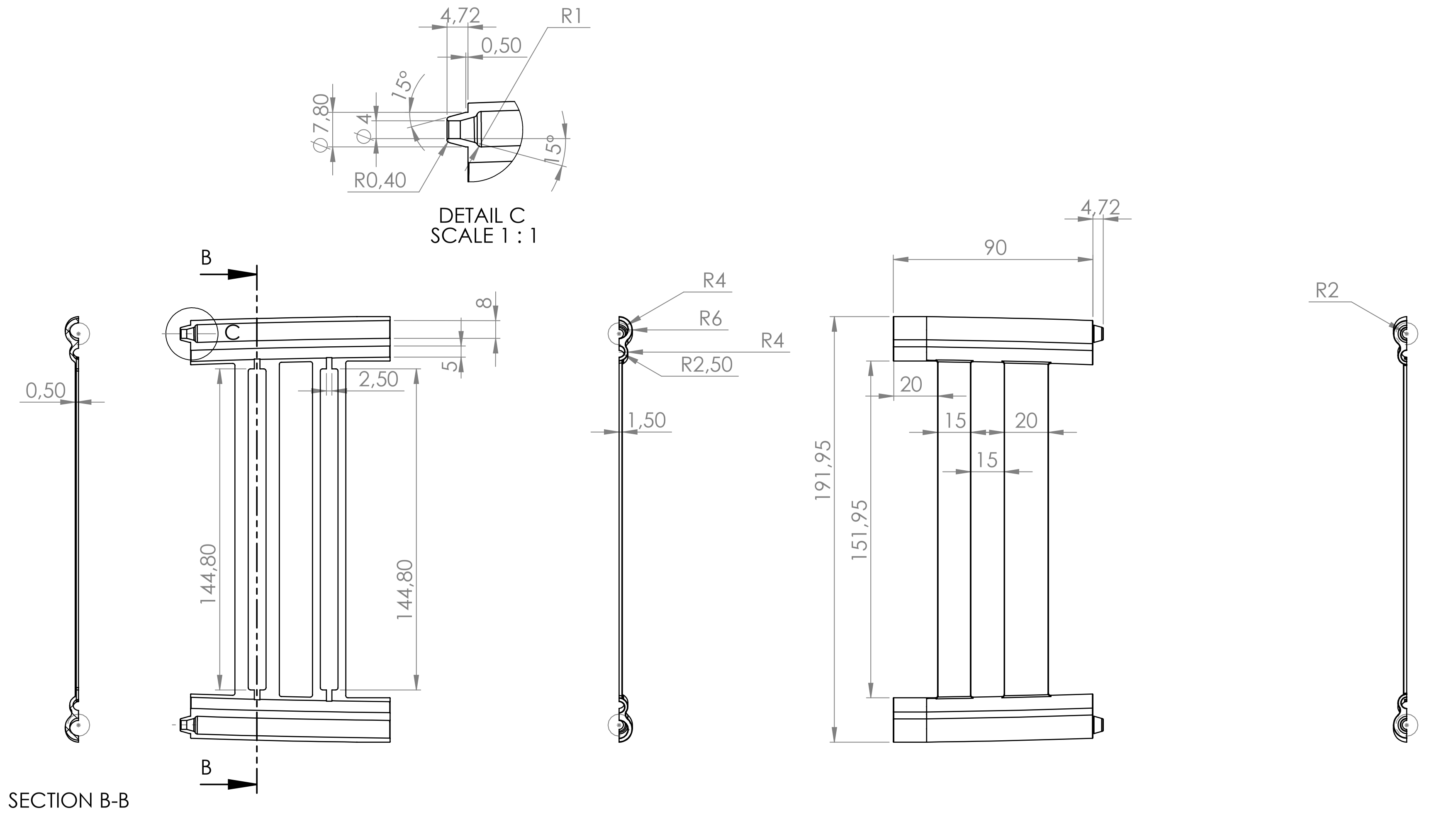
The worst areas of stress are found at the foundation of snap fits as shown in the following pictures.



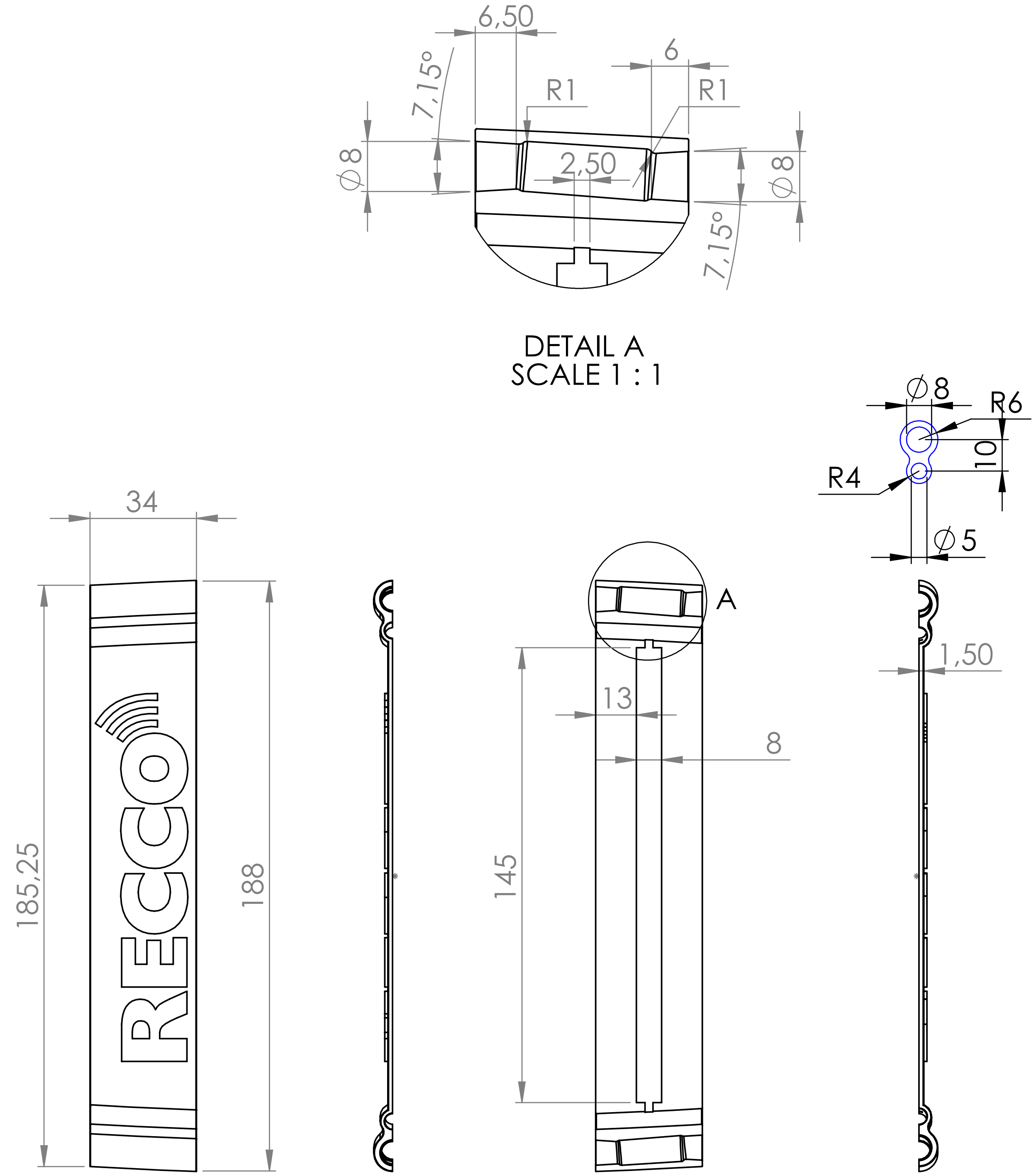
The area directly under the snap fit shows to be the weakest area and caution is needed for further development.

Appendix XIII– Technical drawings

In this appendix the technical drawings over the final design are presented.



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Ra 6 TOLERANCES: ±0.5 LINEAR: ANGULAR:	FINISH: First part of extended antenna, symmetric geometry		DEBUR AND BREAK SHARP EDGES R 0,5	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE: Antenna part 1	
DRAWN	Olle Berg		20140811		
CHK'D					
APPV'D					
MFG					
Q.A			MATERIAL: PA	DWG NO.	A3
			WEIGHT:	SCALE:1:2	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: √Ra 6 TOLERANCES: ±0.5 LINEAR: ANGULAR:	FINISH: Middle part of extended antenna, symmetric geometry	DEBUR AND BREAK SHARP EDGES R 0.5	DO NOT SCALE DRAWING	REVISION

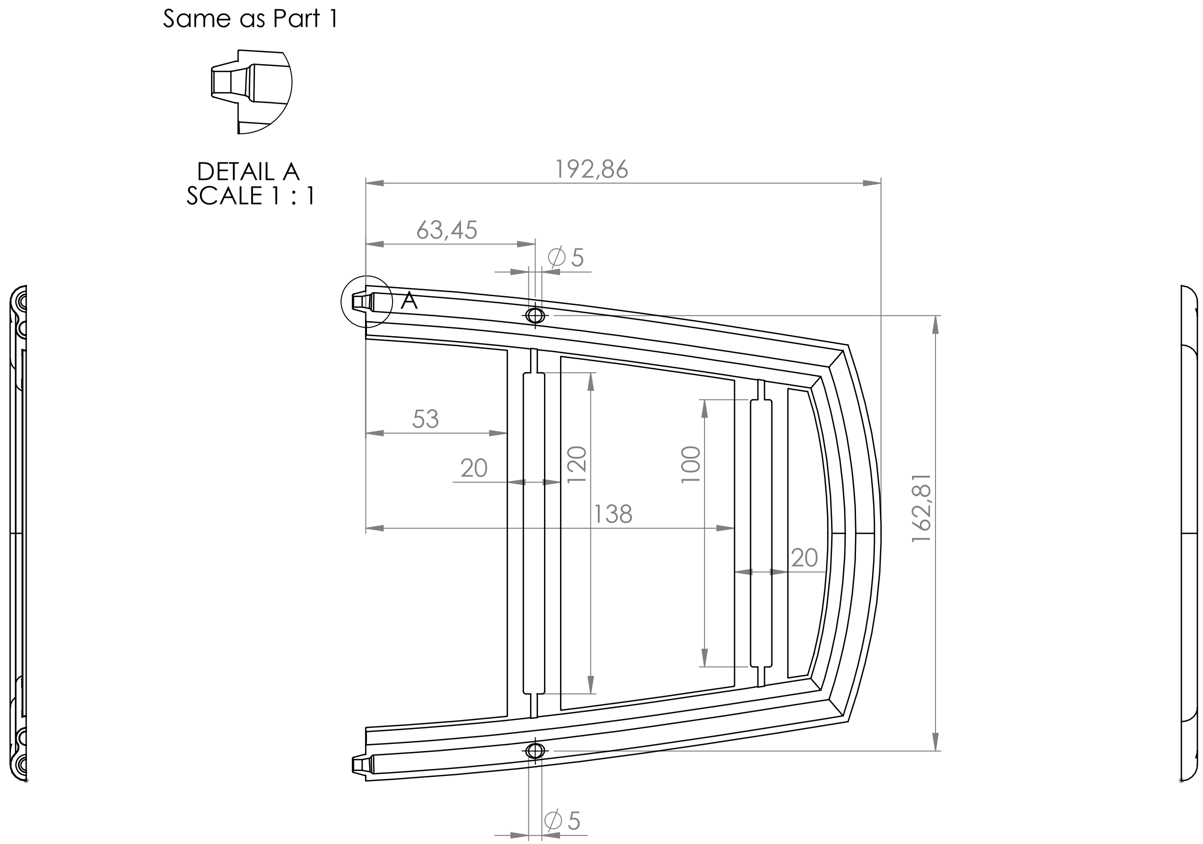
	NAME	SIGNATURE	DATE	
DRAWN	Olle Berg		2014-08-11	
CHK'D				
APPV'D				
MFG				
Q.A				MATERIAL: PA
				WEIGHT:

TITLE:

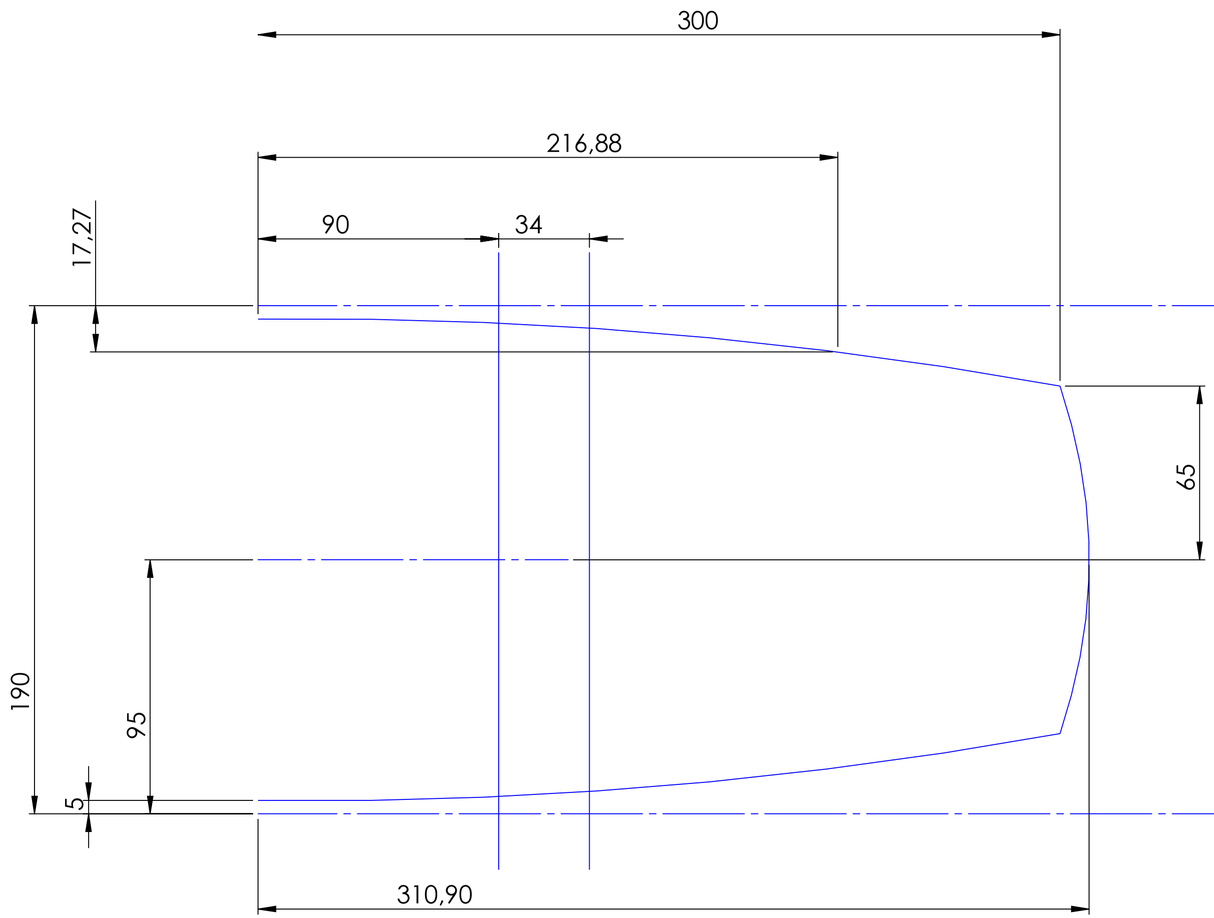
Antenna part 2

DWG NO. 3 — A4

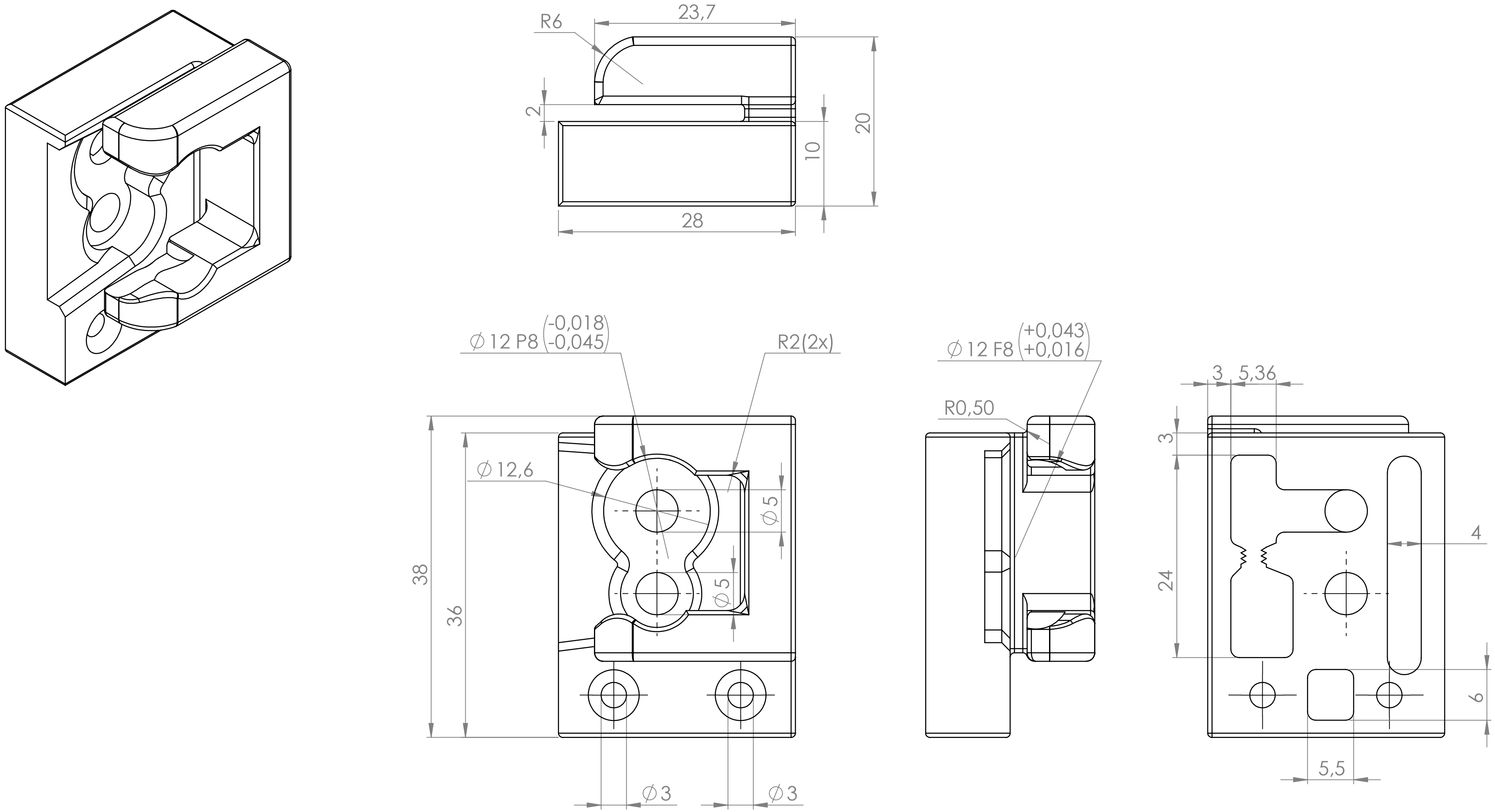
SCALE:1:2 — SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Ra 6 TOLERANCES: ±0.5 LINEAR: ANGULAR:	FINISH: Third part of extended antenna symmetric geometry		DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE: Antenna part 3
DRAWN	Olle Berg		20140811		
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL: PA	DWG NO. A3
				WEIGHT:	SCALE:1:2 SHEET 1 OF 2



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Ra 6 TOLERANCES: ±0.5 LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE	TITLE: Sweep profile of antenna	
DRAWN	Olle Berg		20140811		
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	DWG NO. A3
				WEIGHT:	SCALE:1:2 SHEET 2 OF 2



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: √Ra 6 TOLERANCES: ±0.5 LINEAR: ANGULAR:	FINISH: Upper snap fit		DEBUR AND BREAK SHARP EDGES R 0,5	DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE	TITLE:	
DRAWN	Olle Berg		20140719	Upper snap fit	
CHK'D	Johan Bergström				
APPV'D					
MFG					
Q.A			MATERIAL: Acetal	DWG NO.	A3
			WEIGHT:	SCALE:2:1	SHEET 1 OF 1