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Master Thesis

A Concept Proposal of a New Generation Operator Panels

Karl Löfgren & Henrik Nilsson

Machine Design • Department of Design Sciences • LTH • 2009
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Preface

The Master Thesis, *A Concept Proposal of a New Generation Operator Panels*, was started in September 2008 and finished in February 2009. The project was assigned by the hardware development department at the *Beijer Electronics Products AB*. The involved departments at *Lund University* were *Machine Design* and *Industrial Electrical Engineering and Automation*.

Foremost we would like to thank our supervisor Robert Nordström and his colleague Andreas Sjölin at *Beijer Electronics*. Thank you for your tireless efforts in answering our questions. We would also like to thank the rest of the staff at the hardware department at *Beijer Electronics* Niklas Ekendahl, Henrik Kristensen, Paul Larsson, Agneta Nalepski, and Lars Persson for their help. Thank you, Ola Andersson and Tommy Håkansson at *Beijer Electronics* who have given us helpful remarks during the concept generation process.

At LTH we would like to thank our supervisors Per-Erik Andersson and Gunnar Lindstedt for their help and guidance. Also some external experts at LTH were consulted during the process and deserve a thank you. They are Karin Andersson, Mats Andersson and Lanny Kirkhorn from the division of *Production and Materials Engineering* and Magnus Haake from the division of *Ergonomics and Aerosol Technology*.

Lund, 23 January 2009

Karl Löfgren and Henrik Nilsson

Abstract

This project was done for the company *Beijer Electronics Products AB* and the task was given by the hardware development department of the company.

The project was about developing a concept proposal for a new generation operator panels. This was done to inspire the product developers at *Beijer Electronics* with innovative ideas before the actual operator panel development.

More in detail the objective of the project could be divided into three main parts:

- Generating a concept proposal
- Further development of the concept proposal
- Making a basis for a future input unit prototype (a HID) for the generated proposal

During the first part, 26 concept proposals were generated after research and brainstorming. The proposals were first evaluated by the project group and then presented to some representatives from *Beijer Electronics*. The representatives decided that the project group should further develop two of the concept proposals.

During the further development, 3D CAD models were done. A third concept proposal was derived from one of the first two on the initiative of the project group. A CAD model of the new proposal was also done. Investigations were made on which materials and manufacturing methods could be used for the parts of the concept proposals. The competing materials and methods were evaluated and the best ones were presented in the report.

The third part of the project consisted of making a basis for a future input unit prototype. In this part theory about capacitive touch sensing was researched and explained. Also guidelines on how to make PCB with a touch sensing application was researched and described.

Keywords: operator panel, *Beijer Electronics*, HID, concept proposal, HMI, prototype

Sammanfattning

Det här examensarbetet har utförts på avdelningarna *Maskinkonstruktion* och *Industriell elektroteknik och automation* vid Lunds Tekniska Högskola från september 2008 till februari 2009. Uppdragsgivare har varit *Beijer Electronics* som är en internationell koncern verksamma inom området automation.

Uppdraget som utfördes för *Beijer Electronics Products AB* på avdelningen *Hardware Development* bestod av tre delar. Det första delmålet bestod i att ta fram nya koncept för framtida operatörspaneler. De framtagna koncepten skulle följa den i rapporten så kallade ”building block”-principen. Den här principen innebär att koncepten ska kunna uppfylla kunders olika behov av inmatning genom att valbart antal inmatningsmoduler byggs på en basenhet. Även moduler med andra funktioner än inmatning kan ingå i den här principen.

Den andra delen av arbetet bestod i att vidareutveckla de genererade koncepten till illustrativa 3D modeller och att tänka igenom materialval och tillverkningsmetoder för de ingående komponenterna.

Den sista delen av projektet gick ut på att tillverka en prototyp av en inmatningsenhet. Senare visade det sig att en prototyp inte var möjlig att tillverka vilket ändrade målformuleringen och det presenterade resultatet.

Konceptgenereringen utfördes efter metodik utvecklad av Ulrich och Eppinger[1]. Eftersom *Beijer Electronics* önskade innovativa idéer ledde det till att många koncept innehöll ny obeprövad och blev bortvalda eftersom de var orimliga. Resultatet blev 26 koncept varav 2 valdes till vidareutveckling av representanter från *Beijer Electronics*. De koncepten som gick vidare påminner om dagens operatörspanel med ändringar i den mekaniska designen för att kunna använda sig av påbyggbara moduler.

Under vidareutvecklingen av de två valda koncepten ritades de upp som 3D-modeller i *Pro/ENGINEER*. Under arbetet med att lösa detaljproblem i koncepten framkom ännu ett koncept på projektgruppens initiativ som togs med i vidareutvecklingen. Materialval och tillverkningsmetoder för de olika delarna i koncepten har valts med hjälp av diagram och fakta från materialdatabasen CES[2]. Inga av valen innebar några större förändringar i

[1] Ulrich, Karl T. and Eppinger, Steven D., authors of the textbook *Product Design and Development* 2004

[2] CES EduPack 2008, A material database software made by Granta Design.

materialval och tillverkningsmetoder för *Beijer Electronics* gentemot deras tidigare generationer operatörspaneler. Ramen i de utvecklade koncepten ska pressgjutas i aluminium. Fönstret till koncepten ska tillverkas i glas. Mindre detaljer ska formsprutas i lämplig plast.

Arbetet med de tre kvarvarande koncepten avslutades med att 3D-modeller och material och tillverkningsmetoder presenterades för handledare och personal på mekanikavdelningen på *Beijers Electronics* kontor i Malmö.

Arbetet med att tillverka en prototyp av en inmatningsenhet inleddes med en del efterforskningar inom området kapacitiv touch-detektering, dvs att inmatning med fingrar detekteras med hjälp av kapacitansförändringar. Ett företag som säljer lämpliga mikroprocessorer för att hantera touch-tekniken hittades. Deras touch-teknik studerades med hjälp av dokument på deras hemsida och utvecklingskort från företaget som tidigare hade införskaffats av *Beijer Electronics*.

Under arbetets gång specificerades målet att tillverka en inmatningsenhet som en touchpad baserat på ett kretskort med en mikroprocessor som hanterar multitouch (teknik för att kunna detektera mer än två fingertryckningar samtidigt). Arbetet med prototypen innebar att designa ett kretskort i programvaran CADSTAR. När det förberedande arbetet med prototypen i princip var färdigt visade det sig tyvärr att prototyptillverkningen var tvungen att avbrytas eftersom leverantören av den aktuella mikroprocessorn inte hade färdigutvecklat programvaran för att programmera den med.

Vid det här skedet formulerades ett nytt mål som innebar att det redan utföra arbetet skulle redovisas i form av en guide för hur *Beijer Electronics* skulle kunna tillverka en fungerande prototyp i framtiden.

Resultatet av den sista fasen blev alltså, efter omformulering av målsättning, en teoristudie beskrivande hur *Beijer Electronics* lämpligen ska tillverka en framtida prototyp av en inmatningsenhet. Teoristudien innehåller en del praktiska experiment som utfördes på de tidigare nämnda utvecklingskorten.

Table of Contents

1 Abbreviations

A/D – Analog-to-Digital
API – Application Programming Interface
CAD – Computer-Aided Design
CapSense – Capacitive Sensing
HID – Human Interface Device
HMI – Human-Machine Interface
I/O – Input/Output
I^2C – Inter-Integrated Circuit
IIR – Infinite Impulse Response
ITO – Indium Tin Oxide
LED – Light Emitting Diode
PCB – Printed Circuit Board
PSoC – Programmable System-on-Chip
RF – Radio Frequency
SNR – Signal-to-Noise Ratio
USB – Universal Serial Bus
USBFS – USB Full Speed
USBUART – USB Universal Asynchronous Receiver/Transmitter
VESA – Video Electronics Standards Association

2 Introduction

This Master Thesis was done for *Beijer Electronics Products AB*. The general purpose of the Master Thesis was to generate an innovative concept on how a future operator panel could look like.

Beijer Electronic Products AB is a multinational group with subsidiaries in 14 countries, which has over 600 employees and annualized sales of over 1 billion SEK. The Company is divided into three different business areas: Automation, HMI Products and Industrial Data Communications (IDC), which are described shortly below:

Beijer Electronics Automation – Markets and sells automation solutions to customers in the Nordic and Baltic regions.

Beijer Electronics HMI Products – Develops, markets and sells operator panels to customers worldwide.

Beijer Electronics IDC – Develops, markets and sells data communication solutions to customers worldwide.

The operator panels are meant to be used in various applications to make human beings able to operate machines and processes. The panel of today is exposed to different problematic environments, e.g. food, car industries, workshops and in marine and offshore applications.

The *EXTER* series are the most recently developed series of operator panels and has been sold by *Beijer Electronics* throughout the last years (See *Appendix I*). To still have an attractive product for the customers, *Beijer Electronics* is interested in what the future generation of operator panels should offer.

Many of the customers that have bought operator panels from *Beijer Electronics* required that the panel should be customized to their specific needs, e.g. more buttons etc. Modifying operator panels for specific needs is expensive for *Beijer Electronics*. Therefore the requirement for a new concept of operator panels is that the panel easily can be modified. This can be achieved by having a panel that could be optimized for the customer only by adding one or more extra units. *Beijer Electronics* found it very important that this so called “building block” principle was taken into account during the concept development phase performed in this Master Thesis.

Furthermore, the customer should be able to alter the input buttons layout, e.g. a button should be possible to be changed in size and functionality and moved. The input buttons should be placed on a separate building block, a so called HID. It should be evaluated how this HID would work with capacitive touch technology.

3 Objective

The objective of the project is to generate a concept proposal of a new generation operator panels. The company which gave the assignment, *Beijer Electronics*, foremost wants innovative ideas that can inspire their development of the new generation panels that will be done within the next few years. Hence, the most important part of the project is the actual concept generation. The best concept from the concept generation should be presented as illustrative as possible and preferably as a 3D model in *Pro/ENGINEER*. Material suggestions and manufacturing methods should also be proposed for the concepts.

The concepts should be generated using the “building block” principle which means that the operator panel should be easy to customize by simply adding needed building blocks to a base unit. While generating the concepts, suggesting materials and manufacturing methods these words should be taken into consideration as much as possible: flexibility, industrial adaptation, simplicity, cost efficiency, customization and environmental friendliness.

The remaining time of the project should be spent on making a basis for a future input unit prototype (a so called HID). This includes drawing up guidelines in general on how to make a PCB that is handling the input functionality with capacitive touch sensing. The theory behind capacitive touch technology and how to get a working touch sensing method should be presented. Also some more practical studies should be performed to show how capacitive touch technology and USB communication between an input unit and a computer works. For these tasks some evaluation equipment are supplied from *Beijer Electronics*.

3.1 Original Objective (before it was changed)

The objective of the project was modified the 27th of November 2008. Before the change a functional prototype of the input unit was meant to be developed. It was discovered that the programming software for the microprocessor, that was meant to be used in the design, was not fully developed. That lead to the termination of the prototype development. Instead the objective of “making up a basis for a future prototype input unit” replaced the original one. The work that was done before the termination, the schematic and CAD designs of the PCB, is still presented in the report as guidelines on how to make a HID.

3.2 Delimitation

The generated concepts do not need to be presented with detailed drawings. Instead a simple 3D CAD model, which shows the idea at a principle level, should be presented. The 3D model does not have to include neither mechanical nor electrical details such as ventilation or placing of cables. The reason for this is that *Beijer Electronics* only want inspiration for their upcoming concept development. They find it more important that the project group use the time developing the prototype input unit.

The objective of selecting materials and manufacturing materials does not have a high priority, according to *Beijer Electronics* project supervisor[3], and should therefore only be achieved in an extent that the project timetable allows, i.e. it should not intrude on the time allocated to other objectives.

The original objective did include actually making a prototype of a HID, the new objective does not.

[3]Nordström, Robert, electronics designer at the hardware department, *Beijer Electronics*

4 Method

This project was done using the product development method of Ulrich and Eppinger. However, the method was adapted for the application and only chosen parts were used (See figure 1).

4.1 Project Disposition

The project disposition is derived from the structure of Ulrich and Eppinger's method.

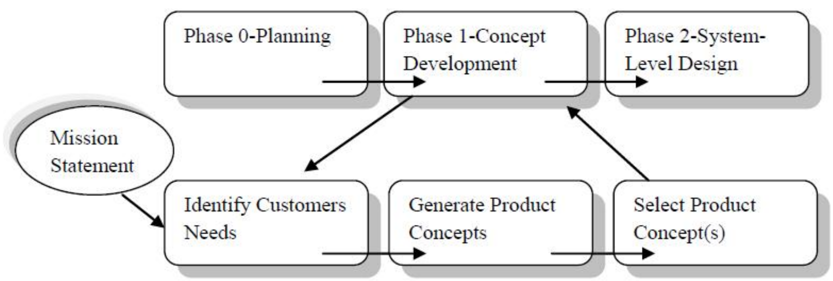

Figure 1 - Project phases in this project

4.1.1 Phase 0 – Planning

The planning phase is meant to consist of five steps where, among other things, possible projects are identified and a project is chosen. In this Master Thesis this is not applicable because a project already is chosen. The planning phase, in this application, only consists of making a project description on the basis of the project specification supplied by the company as a pretext to the project. A timetable should also be made, though. The project description and the timetable are not presented in the report. However, the chapter *Objective* is based upon the project description.

4.1.2 Phase 1 – Concept development

In this phase, many of the steps from the method have been used to create concepts. According to Ulrich and Eppinger an objective specification should, among other things, be written with various requirements and preferences ranked considering the customers. Since the project's sole objective is to develop a concept proposal and not a sellable product, an objective specification in this way was unnecessary. Instead of ranking the requirements and preferences of the concept, just some needs considering the customers were ranked.

The concept development phase in this project was divided into the main parts *Identifying Customers Needs*, *Generating Product Concepts*, *Generated Concepts* and *Concept Selection* derived from figure 1.

4.1.3 Phase 2 – System-level design

After choosing one or more concepts these were further developed to be closer to a sellable product. It was in this phase more detailed models were done in *Pro/ENGINEER*. Proposals of manufacturing methods and material selection were also made. Research about how the electronics of the HID should be designed and CAD designs of a possible future HID prototype were done.

The system-level design was divided into the main parts: *Concept Designs*, *Manufacturing Methods and Material Selection* and *A Basis for a Future HID Prototype*.

5 Concept Development

In this chapter the needs of the customer is established and the methods for getting inspiration for brainstorming about new concepts is explained. In the end the result of the brainstorming is briefly reviewed.

5.1 Identifying Customer Needs

This Master Thesis was done more or less like a consultant project for the company *Beijer Electronics*. The correlate to the customer in this case was *Beijer Electronics*. Fulfilling the needs of *Beijer Electronics* was therefore the primary objective of this project although considering the user of the product was also necessary for the development of a successful concept.

A natural step in the work of identifying customer needs would have been some kind of research for example interviewing users of the product or studying the use of the product in an industrial environment. Interviewing the users of the product was according to Robert Nordström[4] not worth the effort. Robert Nordström thought the results would be useless because the users of the product would only suggest improvements to the already existing ideas and this would not help inspiring new concepts. To strengthen his argument he provided the project group with a compilation of some interview answers. The interviews were performed by the salesmen at *Beijer Electronics* and the persons who had answered the questions were customers of their products. Based on Nordström's statement and the interview results the project team decided that no kind of new interviews should be performed. However, the most important of the old interview opinions were put into a table (See table 1 in *Appendix C*) and interpreted by the project group. The main reason to present some of the interview answers is not to restrain the concept development but just to keep in mind during the process.

Table 2 (*Appendix* C) contains *Beijer Electronics*' needs from their project description. To get more reasonable needs the project team made their own conclusions from the project description which is based upon discussions with the supervisor Robert Nordström. The conclusions are also presented in table 2 (*Appendix* C).

Because the needs of *Beijer Electronics* were not that detailed, it seemed like a good idea to investigate in what environments the operator panels should be used.

[4]Nordström, Robert, Supervisor at *Beijer Electronics*, Personal conversation 22nd September 2008

The operator panels of the current product series, the *EXTER* series[5], are used in many different environments and applications. You can find a *Beijer Electronics* operator panel everywhere from food industries to oil rigs (Robert Nordström).

Considering that the operator panels are used in many different environments caused suspicion that table 2 in *Appendix C* does not cover all of the customer needs. It is possible to find more needs by visiting some of the customers and study the use of the product in an industrial environment. The project group felt that there was no time to visit customers, though. Instead a shorter discussion was held among the group aiming to predict the possible problems the operator could have operating the panel, the result is shown below. The result of the discussion were taken into account during the concept generation phase.

Noise:
The user of the panel requires some kind of feedback when pushing buttons. In noisy environment it is not sufficient with only a sound signal. It is a possible solution to use lights, LED: s or some kind of vibration.

Vibrations:
To use a feedback with vibration technique is not appropriate in an environment with a lot of vibrations. In an environment with vibrations the whole panel must be designed to handle the vibrations. Maybe the buttons have to be extra large so the user can operate without difficulties.

Dust and dirt:
The operator panel should be easy to clean. Table 2 (in *Appendix C*) states that it is very important that there are no edges or cavities were micro organisms can grow. The frame and front have to prevent dust and dirt to get into the panel.

Liquids:
It is possible that the panel is exposed to liquids of various types. There might even be environments where the panel is exposed to chemicals.

Operators with gloves:
In many industrial environments the work requires gloves to protect the hands of the worker. The input unit should be possible to configure for operation with gloves.

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[5] The *Exter* series is the most recently developed series of operator panels released by *Beijer Electronics (*See *Apendix I)*

Moving the panel:
In some applications operating the panel could be done more smoothly if the panel or parts of it are moveable. One example is to use a portable input unit. Another possibility is to have the whole operator panel as a moving piece on an arm.

Ergonomics:
The operator panel must be comfortable to use even in longer periods of time.

Sun light:
Most environments are exposed to daylight from windows. It is important that the operator panel is possible to view at all times.

5.2 Generating Product Concepts

5.2.1 Search externally

The external research was done in different steps and consisted of interviews of external experts, an educational visit, benchmarking and a product research.

Interviewing external experts
The experts that were interviewed were Gunnar Lindstedt[6] and Magnus Haake[7].

Gunnar Lindstedt who is one of the two supervisors from LTH, was interviewed during a regular status report meeting. The questions asked were if he had any ideas about new concepts to an operator panel and if he knew any interesting material such as literature or any old Master Thesis that could inspire to new ideas.

Gunnar inspired to one concept proposal. He also recommended an old Master Thesis written by Anders Lyddby[8]. Gunnar suggested a discussion with Mangus Haake who was the supervisor for the thesis that Lyddby wrote. Magus Haake has a great deal of knowledge in the field of science of HMI.

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[6] Lindstedt, Gunnar, Associate Professor and Supervisor for this Master Thesis, Institution of Industrial engineering and Automation (IEA) at the Lund University. Personal conversation 23/9 2008.

[7] Haake, Magnus, doctoral candidate, Master of engineering, Institution of ergonomics and Aerosol technology. Personal conversation 25/9 2008

[8] Lyddby, Anders, author of the Master Thesis
Analysis of the usability of the Human-Machine Interface in the Tetra PlantMaster 2008

The concept proposal that Lindstedt suggested was based on a panel which is operated like a modern cell phone with a multitouch interface. Similar ideas were already thought of but were dismissed with the argument that the problem solving related to this kind of concept was on a software level and did not really fit into the frame of this Master Thesis. It also did not fulfil the requirement with the “building block” principle. However, in this concept it is possible to get less or more input area through configurations in the software. Lindstedt remarked that the problem solving did not only contain software problems. He explained that the interaction between the human and the panel was an HMI problem that must be considered before the software was created. For example how the operator would navigate with only finger movement is an HMI problem. Based on these opinions several new concepts were created which involved touch technology and these are presented in chapter 1.

The purpose of the interview with Magnus Haake was to get suggestions of literature which covers the area of HMI. It was needed for the new concepts based on touch technology.

The conclusion of the discussion was that it probably would be a waste of time to read theory on HMI. The HMI theory has not been changed for a long time and it would probably not contain any discussion about the touch technology. HMI is a science about making the interaction between human and machine as efficient as possible and the theory does not consider the touch technology aspects. Haake inspired to a new concept by mentioning eye-tracking, a relatively new technology for operating machines. Eye-tracking technology is used in the concept *Proposal 25* (See *Appendix A)*. Haake also mentioned a flat rubber keyboard which is a product that is on the market today. The idea with flat rubber keyboards are used in the concept *Proposal 19* (See chapter 6.3.2*)*. (Haake)

Educational visit

To get new ideas and inspiration for new concept proposals an educational visit was done. Two well-known home electronics supplier chains were visited 23/9 2008. Different user interfaces in electronic products commonly used by the public today were examined. Many interesting details were noted. Some of them could be used in phase 2 (System-Level Design) where the chosen concept would be further developed. One detail actually resulted in the new concept *Proposal 21* (See chapter 6.3.4*)*. The inspiration for this concept was a refrigerator with a built-in TV screen which was possible to slant on a wall hold.

Benchmarking

A benchmarking was done early in the concept development phase. The benchmarking involved research of products from *Beijer Electronics* competitors. The material was found on the competitors' websites. *Beijer Electronics* did also supply the project team with some older operator panels. The project group's conclusion of the benchmarking was that operator panels in general look very similar and have comparable functions independent of the manufacturer. One remarkable observation was that some competitors have several models of portable panels while *Beijer Electronics* only have one. Another observation was that some competitors have panels adjusted to be mounted on stands, in wagons, suspended in the ceiling etc. Beside these observations the benchmarking did not result in any new concepts.

Product research

A research of unrelated products on the internet was done by the project group to get inspiration and ideas for new concepts. The unrelated products that were especially interesting were cell phones, MP3-players and Hifi-equipment. One company manufactured projected keyboards with infrared technology. These projected keyboards generated concept *Proposal 23* (See chapter 6.3.6). Other concepts were inspired by the idea of using projected images. One of the more extreme projector applications found on the internet was a cell phone with a 42" projected TV which inspired the concept *Proposal 26* (See *chapter 6.3.9).*

5.2.2 Search internally

During the phase concept development several internal searches were done in the form of brainstorming. The goal with the brainstorming was to generate as many ideas as possible. To get a better result, the brainstorming has been performed both in group and individually.

The first brainstorm

The first brainstorm was the beginning of the phase *Concept Development*. By this time *Beijer Electronics* had not told much about how they wanted the new concept to be. The reason for performing a brainstorm very early without any research was to minimize the risk of being trapped in the same way of thinking as *Beijer Electronics* product developers. There were only two things that were to influence the thinking. One of them was the requirement that the customers should be able to put together an operator panel with different building blocks based on their own needs. The other thing that was to be influencing was the idea of an input unit called a HID unit. The HID unit would be equipped with a touchpad were the size and functionality of the buttons could be configured by the customer.

The result from the first brainstorm is presented in chapter 6.1 and in *Appendix A* (rejected proposals). The generated result consisted of ten concept proposals including sketches, descriptions, advantages, disadvantages and comments. The primary goal with these first proposals was only to get inspiration for the later concept generation. The proposals are not concepts worked-out in detail, they are only fundamental ideas. Under the caption *Comments* opinions and thoughts from a feedback meeting on the proposals are presented. The feedback meeting took place during week 37 in September 2008 and was a discussion between the project group and Robert Nordström and Andreas Sjölin[9] about which concepts to develop further.

The second brainstorm

The purpose of the second brainstorm was to further develop the ideas from the first brainstorm and generate more ideas. Before the brainstorm some work was done to get new inspiration. The work consisted of a benchmarking and a product research which are described in chapter 5.2.1. A guided tour at *Beijer Electronics* gave some glimpses of the panels produced today and some older generations from *Beijer Electronics*. The second brainstorm resulted in six concept proposals presented in chapter 6.2 and in *Appendix A*. Some of the concept proposals are described in detail and others are only fundamental ideas. The comments are the project groups own observations and opinions from a meeting with supervisors Robert Nordström and Andreas Sjölin, project leader Ola Andersson and Tommy Håkansson[10].

The third Brainstorm

The project leader wanted to extend the phase concept generation, because he thought it was necessary to take a few steps back and think more ”outside the box”. More preparation work to get more inspiration was done in the form of interviews of external experts and an educational visit (*Search Externally* chapter 5.2.1). The third brainstorm resulted in nine concept proposals described in chapter 6.3. Many of the new concepts did not fulfil the requirement of the “building block” principle but this was justified with the argument that it was allowed to think outside the box. The new concepts were only using a touchscreen for inputs, but the amount of area for input could still be configured as software HIDs.

[9] Nordstrom, Robert and Andreas Sjölin, Supervisor and Co-supervisor, respectively, *Beijer Electronics*, Feedback meeting w.37 September 2008

[10] Nordström, Robert, Sjölin, Andreas, Andersson, Ola and Håkansson, Tommy, Supervisor, Co-supervisor project leader and Technical Manager, respectively, *Beijer Electronics*, Feedback meeting 17/9-2008.

6 Generated Concepts

In this chapter the proposals generated from the brainstorms are presented, evaluated and eventually the best proposal is selected. Only the proposals that made it through the evaluations are presented in this chapter. The proposals that were rejected are presented in *Appendix A*. An exception, though, are the proposals that were rejected after the third brainstorm and are presented in this chapter.

6.1 The First Brainstorm

6.1.1 Proposal 1 – Inverted laptop

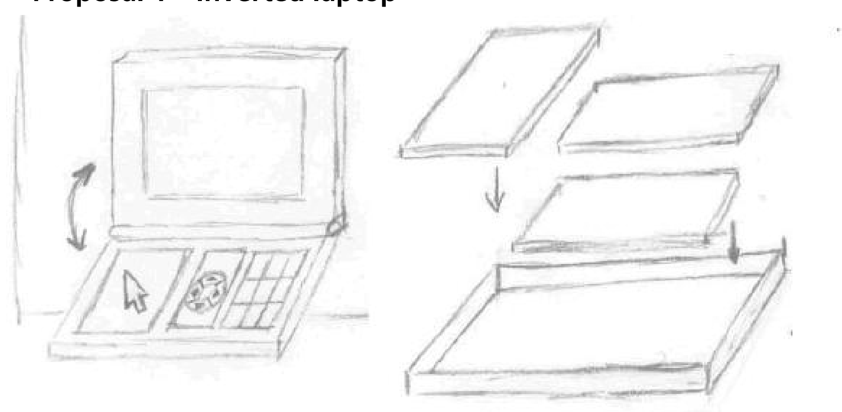


Figure 2 – Sketch of proposal 1

Description:
The concept of this operator panel is very similar to an ordinary laptop except that the display unit is mounted into a wall. The keyboard is placed in a lid that is opened from the display unit. The lid is jointed at the lower edge of the display unit.

The keyboard area can be configured by the customers' needs by placing as many input units into the lid as you need. The lid which has room for a certain amount of input-units has to be filled with dummy pieces if the customer does not want to use all possible space as an input area.

The display unit is mounted into the wall by the same method as the *EXTER* series (See figure 3 in *Appendix I*). The CPU (the computer part of an operator panel) and the other electronics are mounted behind the display in the display unit.

Advantages:
- The HID units and the display can be protected when the operator panel is not used
- Possibility to choose the amount of HID units
- The input area can be adjusted to an ergonomic angle
- The operator panel needs less space when not used
- Adapted to remote and protection lid
- Connected as one unit

Disadvantages:
- Hard to clean because of joints
- The maximum amount of HID units is limited
- The operator panel needs more space when used
- The standardised size of the lid could lead to unused space.

Comments:
This proposal is not interesting as a whole concept but the idea with the lid could be an optional accessory for later concepts.

The proposal could be further developed as an accessory in a concept.

6.1.2 Proposal 4 – Display unit with additional electronics on the back and the HID unit separately

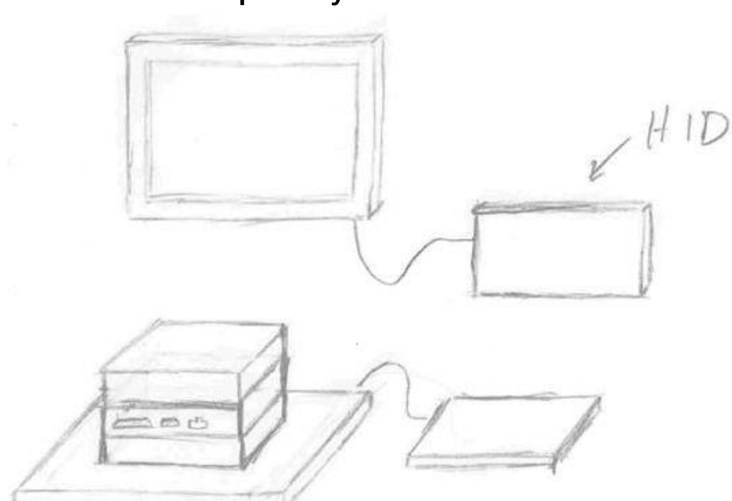


Figure 3 – Sketch of proposal 4

Description:
This proposal is very similar to the *EXTER* series. The electronics is placed behind the display and the whole display unit is mounted into the wall. The big difference is that this proposal has a separate HID unit connected to the display unit by cables. The HID unit is flexible and can be mounted according to the customers' needs.

Advantages:
- Possibility to choose the amount of HID units
- More flexible placement of the concept components
- Easy to clean

Disadvantages:
- Not possible to mount as one unit
- The maximum amount of HID units is limited

Comments:
The proposal is similar to the existing generation of operator panels. A detail that should be changed is that you should have the possibility to mount the HID unit and the display unit as one unit.

This proposal could be further developed.

6.1.3 Proposal 7 – Remote control

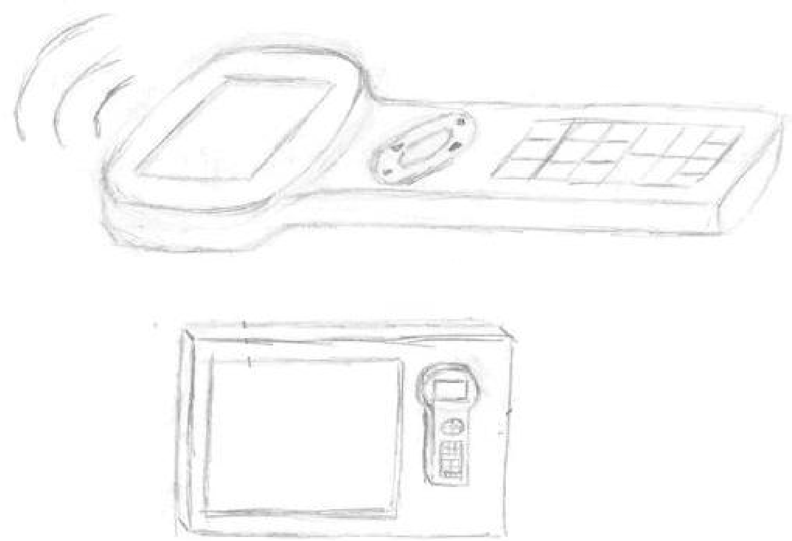


Figure 4 – Sketch of proposal 7

Description:
The operator panel is mounted in the wall and the input is done through a remote control.

The remote could either be placed in a docking station next to the panel or be used as a remote. The remote has two function blocks consisting of one HID area and one display. The HID area could be configured according to the customers' needs. The small display will show the user information about different choices, confirmations when buttons is pushed, error messages etc.

When the remote is placed in the docking station it is protected against dirt and dust by a thin transparent plastic film. The plastic film will allow the user to press the buttons. The docking station will prevent the user from knocking the HID unit to the floor.

The operator panel is fastened onto the wall by the same principal as the *EXTER* series (See figure 3 in *Appendix I*). The CPU and other electronics are placed behind the display.

Advantages:
- Possibility to use the HID unit as a remote or a stationary input device.

- The user does not have to have the panel in sight when operating it

Disadvantages:

- No possibility to choose the amount of HID units (i.e. the "building block" principle is not applied)
- The remote control does not cover the need of buttons
- The docking station makes the panel hard to clean

Comments:
A good idea, the docking-station partially solves the security problem with misplacement. This proposal is not interesting as a whole concept but the idea with the remote could be an optional accessory for later concepts.

The proposal could be further developed as an accessory.

6.1.4 Proposal 8 – HMI unit with a joystick (no touch technology)

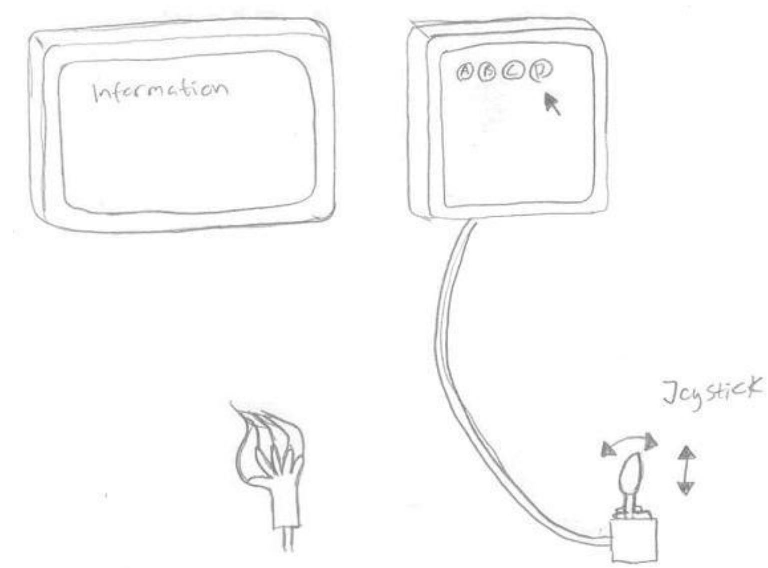


Figure 5 – Sketch of proposal 8

Description:
An HMI device without touch technology can be an advantage in very dirty environments. A joystick or a similar device is easier to clean compared to a display.

A more futuristic alternative is to use a "cyber glove" (a, by the project group, made up notion of a glove with built in technology detecting movement) as an input device. The sketch shows the idea of having a main display to show the present events. Another display unit is used to show the possible input choices. This input display should be possible to configure according to the needs of the customer.

Advantages:

- Easy to clean
- The display units do not have physical contact with the operator

Disadvantages:

- Inefficient and more difficult input movement
- No possibility to choose the amount of HID units (i.e. the "building block" principle is not applied)
- Not possible to mount as one unit

Comments:
This proposal is not interesting as a whole concept but the idea with the joystick or similar alternatives could be an optional accessory for later concepts.

The proposal could be further developed as an accessory.

6.1.5 Proposal 9 – Display and HID unit mounted as one unit

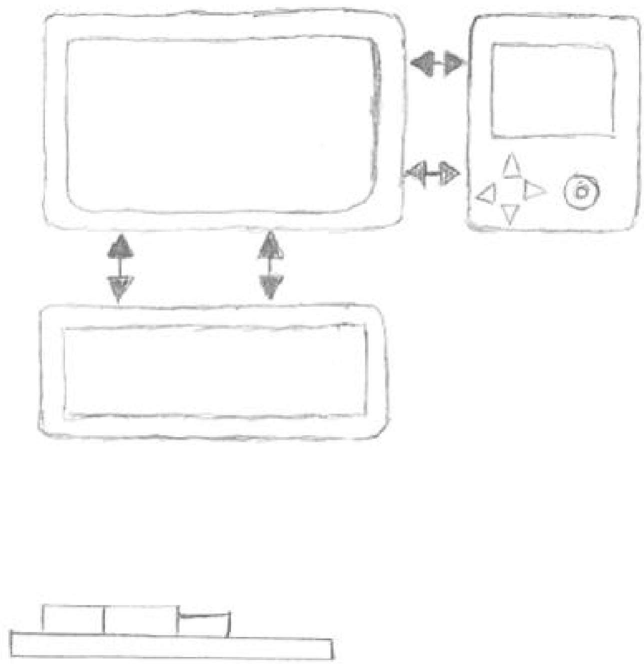


Figure 6 – Sketch of proposal 9

Description:
The idea of this proposal is to have a display as a base unit on which the HID units are docked from different sides. This proposal is not detailed, as an example the docking procedure is not designed. The electronics is placed behind the display unit and are also developed as different building blocks.

Advantages:
- Possibility to choose the amount of HID units
- Possible to mount as one unit
- Flexible (the building blocks can be mounted as one unit or separately)

Disadvantages:
- Hard to clean because of joints
- The maximum amount of HID units is limited
- The docking could be hard to achieve

Comments:
This basic idea is interesting, but the problem with the docking procedure has to be solved.

This proposal could be further developed.

6.1.6 Proposal 10 – The HID and display unit are mounted on an arm

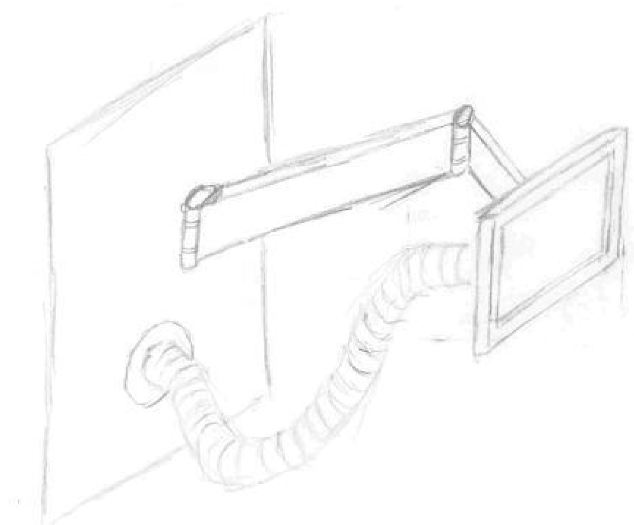


Figure 7 – Sketch of proposal 10

Description:
The goal of this proposal is to have the operator panel on a moveable arm, which can be adjusted in different angles. The inputs are done from a remote or an external HID unit.

Wires and ventilation to the panel goes through a separate pipe. The pipe must be made in a bendable material not to restrain the movements of the arm.

Advantages:
- Adapted to remote function
- Adjustable to an ergonomic position
- The operator panel needs less space when not used

Disadvantages:
- Arm and pipe can be obstructions

- Operator panel must have a protecting cover on the back side to be protected against the surrounding environment
- Not possible to choose the amount of HID units (i.e. the “building block” principle is not applied)
- Not possible to mount as one unit
- The remote control does not cover the need for buttons
- Hard to clean
- Unsafe with a remote (could be misplaced or cause unwanted inputs)

Comments:
This proposal is not interesting as a whole concept but the idea with the arm mounted panel could be an optional accessory for later concepts. There are already standardised moveable arms (VESA arms).

The proposal could be further developed as an accessory in a concept.

6.1.7 Summary of the first brainstorm

In the feedback meeting after the first brainstorm it was decided by the two supervisors at *Beijer Electronics* that two of the proposals (proposal 4 and 9) was to be further developed and combined to one new concept. They also decided that some ideas from the other proposals could be further developed as optional accessories to other concepts. These accessories are:

- Remote control
- Joystick
- Moveable arm (VESA)
- Protective lid

6.2 The Second Brainstorm

6.2.1 Proposal 11 – Display and HID unit separately

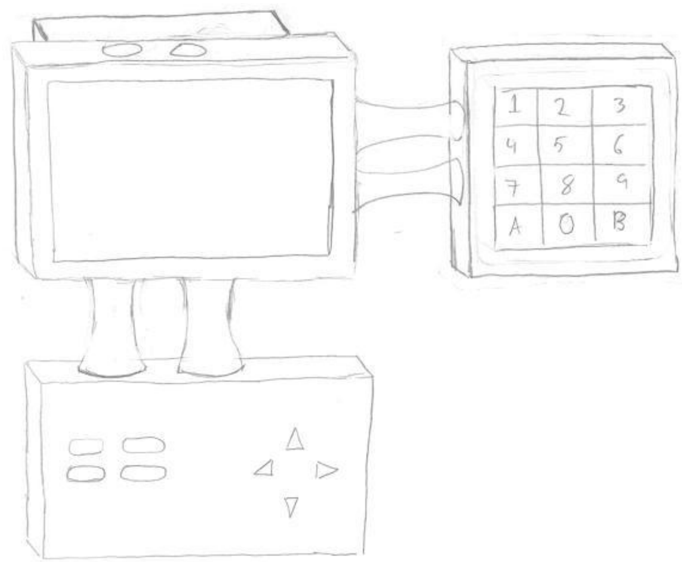


Figure 8 – Sketch of proposal 11

Description:
This proposal is flexible depending on how it is mounted. It is supposed to be possible just to mount the display in the wall and then connect the HID units that are mounted on the outside of the wall with small fixes. If the HID units are mounted outside the wall pipes are meant to be used to get isolation around the cords. If installing all the units mounted in the wall is preferred there is no reason to use the pipes. The proposal allows four HID units to be docked to the display unit.

Advantages:
- Flexible mounting (See *Description*)
- Possibility to choose the amount of HID units

Disadvantages:
- Maximum amount of HID units is limited
- No possibility to mount as a connected unit

Comments:
To mount the HID units on the outside of walls and connecting them with pipes will not serve any purpose. The effect of the pipes would rather be accumulation of dirt. To mount everything in a cupboard and instead connect the display unit and the HID unit with cords is considered to be a possible solution.

The proposal could be developed further.

6.2.2 Proposal 12 – Display unit with HID units docked

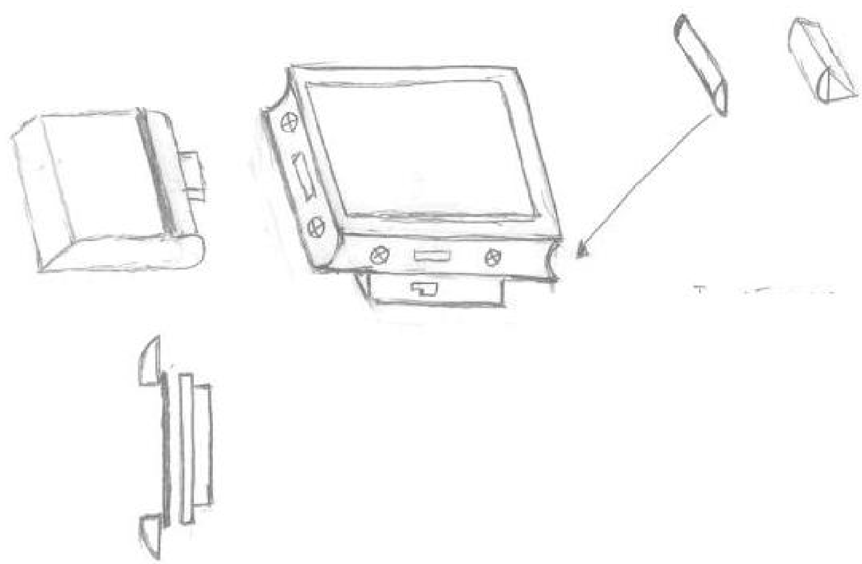


Figure 9 – Sketch of proposal 12

Description:
This proposal means that a display unit with its electronics is mounted onto the wall. HID units can then be docked, on the outside of the wall, into all the sides of display unit. The HID units are only attached to the display unit and not to the wall. With an intelligent design all the joints could be sealed. The empty places for HID units can be filled by a covering unit.

Advantages:
- Possibility to choose the amount of HID units
- Mounted as one unit

Disadvantages:

- The maximum amount of HID units is limited
- The docking could be hard to achieve in a satisfying way
- Hard to clean because of joints
- The HID units cannot be mounted apart from the display unit

Comments:
The proposal could be developed further.

6.2.3 Proposal 13 – Display unit with HID units possible to dock

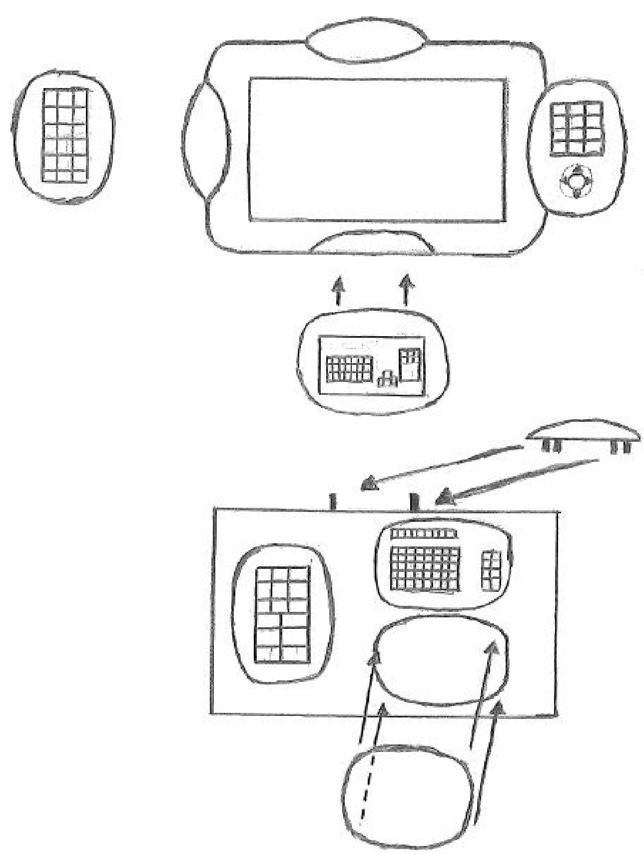


Figure 10 – Sketch of proposal 13

Description:
This proposal is founded upon the principle that the structure of the panel is a display placed in a frame built into the wall like the panels of the *EXTER* series. Then it is expanded on the sides with HID units for input. The HID units though are flexible and are possible to mount into the wall a bit to the side of the display unit or in a so called protection lid.

The frame of the display is to be made in different sizes to fit different displays. Along the sides of the frame there are four holes for docking, so called docking stations. The docking stations are made in the same standardized sizes regardless of the size of the frame. The HID units are mounted onto them. Through the docking station there is a connection made via USB. The connection of the HID and the display unit makes the assembly isolated and gives the impression of one big unit. If the docking station is not used the empty space is filled with a covering unit that seals it and makes it more esthetical.

Around the HID display there is a frame with a strip of rubber on the backside to make the connection between the wall and the docking area sealed.

One type of HID unit will have a docking station for a remote. The remote consists of one part that is a HID and one part that has a small display. The HID part is possible to configure like the other HID units. The display is supposed to notify the user what to do on the panel, what is done and display error messages. The remote will have some sort of protective cover when it is docked.

The HID units can also be mounted into a protection lid. This will function as a keyboard of a laptop. Onto the lower docking station a unit with a hinge is mounted. The lid is attached to the hinge unit. Onto the upper docking station a unit with a locking mechanism is mounted. The mechanism makes the design isolated while the lid is closed. The mechanism works like the one on a laptop except that a rubber strip runs along the edge. In the lid there are three spaces made out to fit HID units. The USB connection is done through the spaces. The HID units are mounted into the spaces in the same way as onto the walls. In that way the lid is isolated while used.

To mount display and HID units the same method is used as in the *EXTER* series (See figure 3 in *Appendix I*). Devices with screws are mounted into holes on the backside of the unit. When the screw is fastened the ledge of the frame is pressed against the wall with the rubber strip in between.

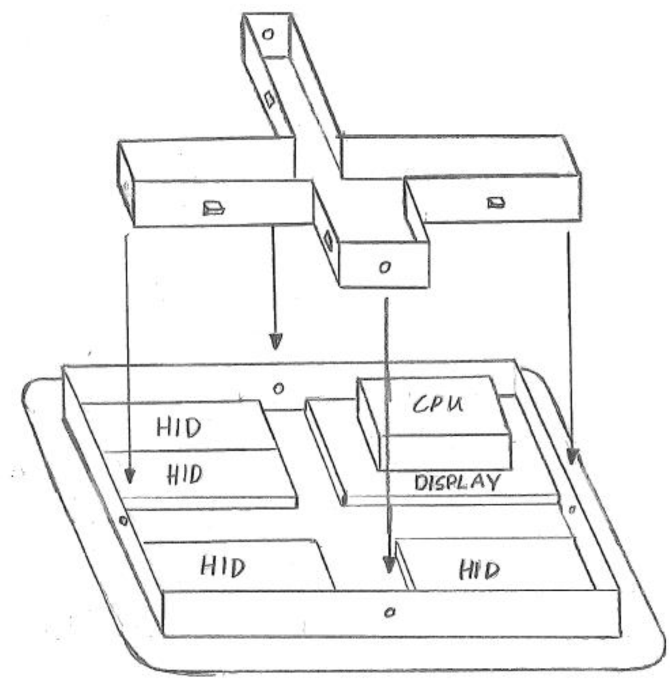
Advantages:
- More standardized units
- Mounted as one unit
- Possibility to choose the amount of HID units
- Adapted to remote and protection lid

Disadvantages:
- Hard to clean because of joints
- The docking itself could be hard to accomplish in an advantageous way
- The maximum of HID units is limited

Comments:
The feedback was positive in general. The concept would maybe be hard to implement because several joints would be needed between the units. It could lead to that the panel would not be properly isolated.

The proposal could be developed further.

6.2.4 Proposal 14 – All the building blocks in the same cover behind one glass window



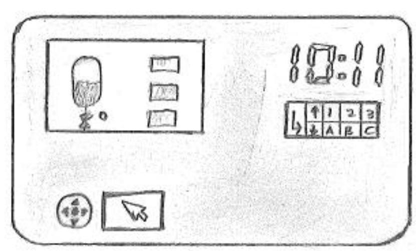


Figure 11 – Sketch of proposal 14

Description:
The idea of this concept is that the display and HID units are placed close to each other behind a glass window. Then it is possible to use their touch function through the glass.

The customer can himself choose how many HID units that should be used and their location behind the glass.

The glass window has a ledge that is supposed to be mated against the wall with an isolating rubber strip in between. The frame is mounted onto the wall in the same way as in the *EXTER* series (See figure 3 in *Appendix I*). Small devices with screws are mounted into holes in the frame and are fastened against wall. The glass is tinted on the backside, where there are no units, to get the effect that the glass is one big display. The frame is made in three different sizes so that the customer will not use more space than necessary.

The units behind the glass are fixed with a plastic fixture and against the walls of the frame. They are fixed through protrusions from the outer walls of the plastic fixture. As the plastic fixture is designed there is a certain amount of spaces for HID units. If a customer does not want to use all of the spaces they are filled with plastic dummies. The frame for the display is suited for the biggest possible display. If a smaller display is asked for, more plastic dummy material is needed. To make it look better with the plastic dummies the glass window is tinted so that they do not show.

The CPU and the rest of the electrics are mounted behind the display.

Advantages:
- Possibility to choose the amount of HID units
- Mounted as one unit
- Easy to clean
- Easy to make a good design
- The frame and the window protect against the surroundings
- Complicates sabotage

Disadvantages:
- A lot of space for mounting needed
- Because of standardized sizes of the frame it could lead to unused space
- Not suited for remote function (no docking possibilities)
- Maximum amount of HID units is limited
- Not flexible because all building blocks have to be within the frame

Comments:
The idea was found interesting. The material for the dummies can be made standardized so that it is already located wherever there is suppose to be display or HID units, and broken off if a unit is needed on that place.

The proposal could be developed further.

6.2.5 Proposal 15 – All building blocks are in the same cover with a detachable front

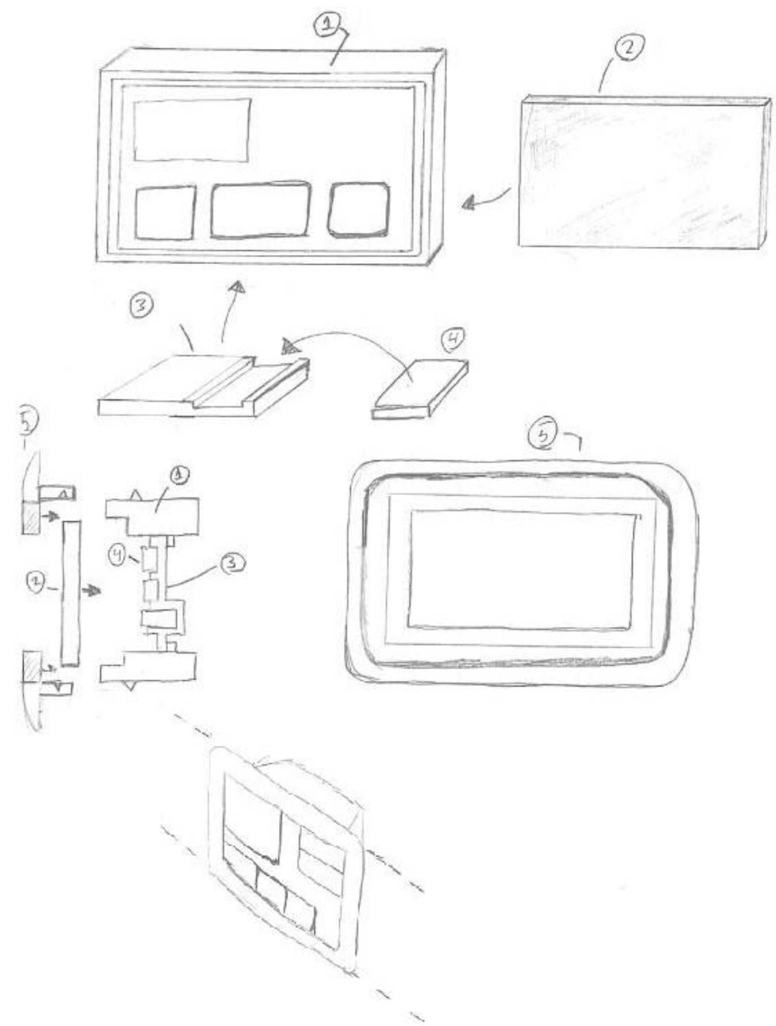


Figure 12 – Sketch of proposal 15

Description:
The proposal is based upon the already explained principle with a frame where the customer himself is able to select display and HID units. The fixture where the units are

placed in is a bit differently designed. A thin glass window is mounted from the front and is fixated by the removable front. The frame will be manufactured in different sizes.

Advantages:

- Possibility to choose the amount of HID units
- Easy mounting and configuration because of removable front and that everything is mounted from the front
- Easy to clean
- Mounted as one unit
- Easy to make a good design
- The frame and the glass window protects against the surroundings

Disadvantages:

- Because of standardized sizes of the frame it could lead to unused space
- A lot of space for mounting is needed
- Not adapted for remote control function
- Maximum amount of HID units is limited
- Not flexible because all building blocks have to be within the frame

Comments:
This proposal is alike others already described. The question is if a removable front is that big of an advantage. A removable front can cause problems with protection against sabotage.

The proposal could be a part of the further development of the similar proposals.

6.2.6 Summary of the second brainstorm

In the second brainstorm there are two concept types that are commonly seen among the ideas that were to be developed further. It was these two concept groups that were presented in a meeting with the supervisor and electronics designer Robert Nordström, project leader Ola Andersson, electronics designer Andreas Sjölin and technical manager Tommy Håkansson.

Concept 1:
The idea of the concept is to mount building blocks behind a glass window so that all the components are gathered in one unit.

The proposals that are included in this concept are 14 and 15.

Concept 2:
The idea of the concept is to have a display unit with the CPU unit attached as the foundation of the concept. Then separate HID units are attached on the sides or into the wall some distance apart. The proposals that are included in this concept are 11, 12 and 13.

6.3 The Third Brainstorm

6.3.1 Proposal 18 – iTerm

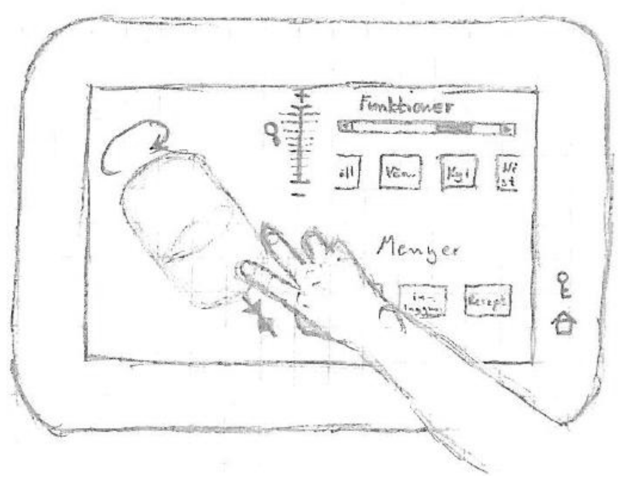


Figure 13 – Sketch of proposal 18

Description:
The panel consists of only a display unit with a touch screen that visualizes the process and deals with the inputs. The operator will be able to use different movements to e.g. zoom which demands multi touch technology. To avoid the panel to be activated by mistake there could be a button lock in the frame area.

Advantages:

- Easy to clean
- Mounted as one unit

Disadvantages:

- All input is done through the software of the panel which could cause a problem when many buttons are needed.
- The touch screen easily gets dirty when inputs are made in dirty environments

- The "building block" principle is only applied through software

Comments:
The configuration of the buttons is completely embedded in the software. This leads to a lot of possibilities and flexibility considering the design of the buttons for the customer. However, this kind of solution without physical building blocks is not a wanted solution by *Beijer Electronics.*

The proposal is to be rejected.

6.3.2 Proposal 19 – Touchscreen with a transparent keypad

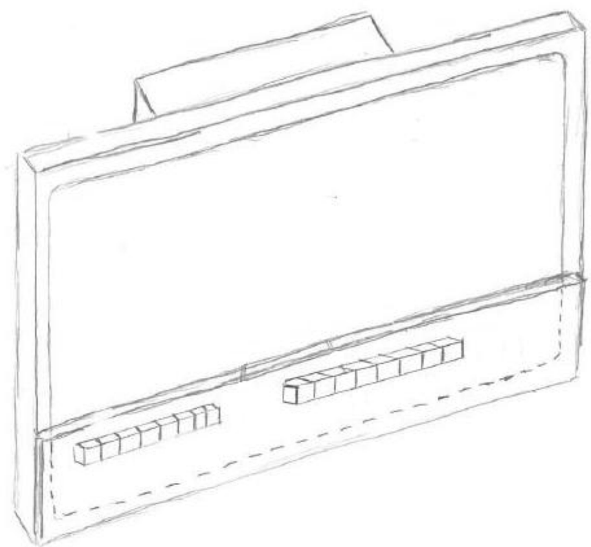


Figure 14 – Sketch of proposal 19

Description:
The proposal uses a display unit with touch technology. The idea is that the customer should be able to mount a transparent plastic protection with protruding rubber buttons. Due to the keypad the user does not need to be in direct contact with the screen. The buttons' functionality differs in every menu of the screen. The keypad will be able to be mounted on different sides.

Advantages:
- Easy to clean
- The touch screen is not affected much by dirty environments

- Mounted as one unit

Disadvantages:

- The software has to be adapted so that the buttons are placed on one side of the panel
- All input is done through the software of the panel which could cause problems when many buttons are needed
- The "building block" principle is only applied through software

Comments:
Some customers may be interested of the protective cover if it is easy and cheap to replace.

The proposal could be developed further as an accessory.

6.3.3 Proposal 20 – Touchscreen with pointer remote and a storage box

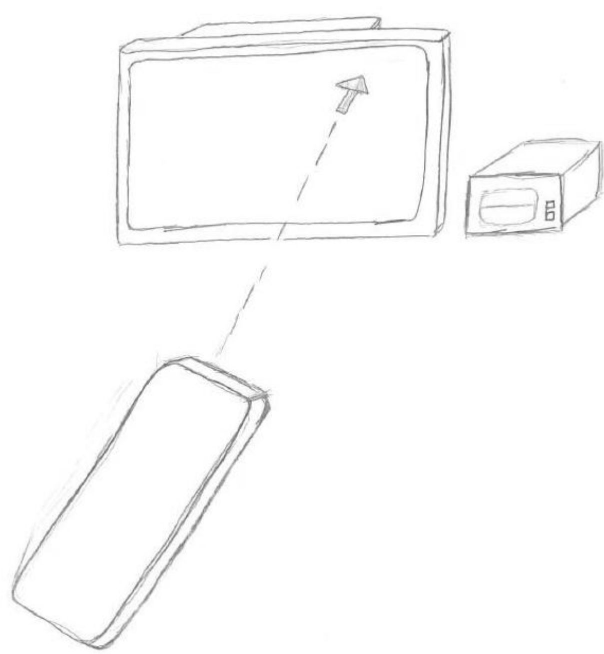


Figure 15 – Sketch of proposal 20

Description:
The remote will function as a pointer. All input is done through the remote control which requires more of the software. The remote control is placed in a storage box when it is not used. To get the remote control out of the box a button is pushed. Both the display and the storage box are mounted into the wall.

Advantages:
- The display is completely free from touch which is suitable in a dirty factory
- Easy to clean
- Ergonomic

Disadvantages:
- All input is done through the software which could cause problems when many buttons are needed
- Could complicate and delay input
- No possibility to mount as one unit
- Unsafe with a remote control (could be misplaced or cause unwanted inputs)
- The docking of the remote control could lead to difficulties in cleaning
- The "building block" principle is only applied through software

Comments:
The main argument for the concept is that the panel will not get dirty was argued against with the statement that the remote control also could get dirty. This could be avoided if the remote would be covered with a replaceable protective cover.

The proposal could be developed further as an accessory.

6.3.4 Proposal 21 – Extensible touchscreen

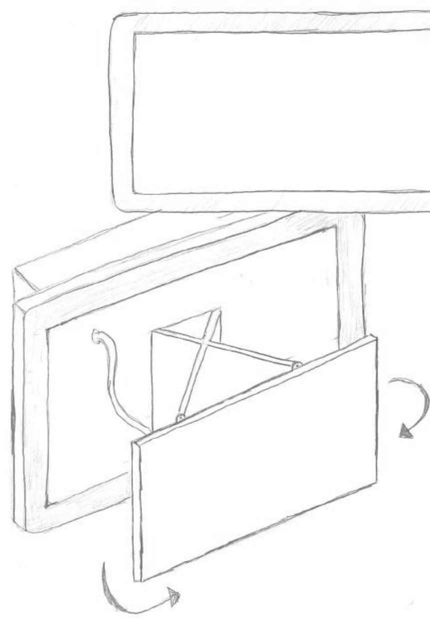


Figure 16 – Sketch of proposal 21

Description:
This proposal consists of a touch screen where all input is done directly through the screen. It is possible to extract the screen on a frame with a light push. When the frame is pulled out it is possible to angle in two degrees of freedom.

Advantages:
- Ergonomic
- Mounted as one unit

Disadvantages:
- All input is done through the software which could cause problems when many buttons are needed
- Hard to clean because of the frame
- A joint between the frame and the display
- The “building block” principle is only applied through software

Comments:
Why not having the whole panel in a frame that works in the same way as the arm behind the display? To make the angling function in this way just makes the design difficult.

The proposal is to be rejected.

6.3.5 Proposal 22 – Touchscreen with pointer stick

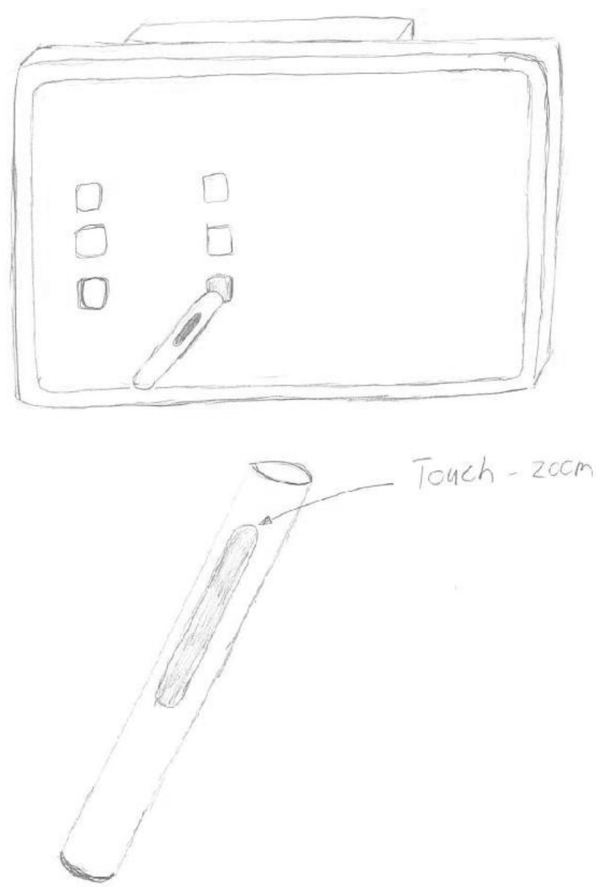


Figure 17 – Sketch of proposal 22

Description:
A display with touch technology is used both to visualize the process and for input. A pointer stick is used so that the user will not be able to touch the screen.

As the picture shows, the pointer stick could possess different functions like volume or zoom (See Figure 17).

Advantages:

- The display is touch free which is suited for dirty industries
- Easy to clean
- Ergonomic

Disadvantages:

- All input is done through the software which could cause problems when many buttons are needed
- Some sort of storage for the pointer stick is needed
- Unsafe with a remote control (could be misplaced or cause unwanted inputs)
- The "building block" principle is only applied through software

Comments:

It is an interesting idea. The pointer stick could be produced cheaply.

It could be further developed as a cheap accessory for panels in dirty environments.

6.3.6 Proposal 23 – Projected keyboard

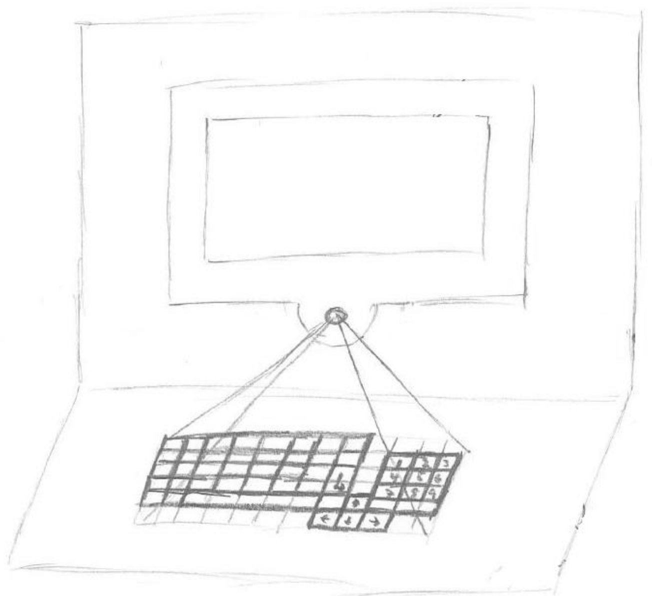


Figure 18 – Sketch of proposal 23

Description:
The panel looks like the ones of the *EXTER* series, built into the wall. There are no buttons on the panel besides possibly on the display that could function as a touchscreen. Below the display there is an infrared projector that projects a keyboard on a surface below the panel.

Advantages:
- The display is touch free which is suited for dirty industries
- Easy to clean
- Mounted as one unit

Disadvantages:
- Could be hard to see the keyboard in rooms with bright light
- New technology that is not reliable
- Must be a surface directly beneath the panel
- Maximum area for buttons is limited

Comments:
It is an innovative idea. It is possible to apply in extreme environments.

The projected keyboard could be developed further as an accessory.

6.3.7 Proposal 24 – Projector with remote control

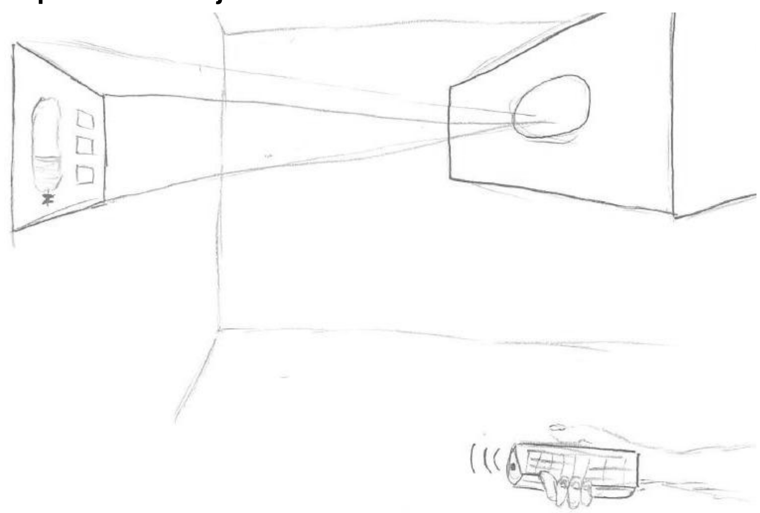


Figure 19 – Sketch of proposal 24

Description:
The display is projected onto a wall or a plane surface with an ordinary projector that is placed behind a glass protection. The electronics including the CPU is attached to the projector unit. To orientate in the program a remote is used. The remote control could be controlling the mouse pointer with a gyroscope (as it is done with the remote control of the Nintendo Wii[11]). The user turns and tilts the remote so that the pointer moves on the display or there is a touch pad on the remote that is used with the thumb.

Advantages:
- The user will not be in physical contact with panel
- The display and electronics are isolated from the surroundings
- The panel is possible to use in an ergonomic way

[11]A video game console made by Nintendo Company Ltd. (Wii, spelkonsolen för hela familjen 2008)

Disadvantages:

- There must be a big clean surface to the projected display
- The air space between the projector and the projection must be free.
- The gyroscope function could be hard to learn
- Maximum HID area is limited (i.e. the "building block" principle is not applied) Unsafe with a remote control (could be misplaced or cause unwanted inputs)
- The "building block" principle is only applied through software

Comments:
The representation of the display could be bad in a bright environment. It is inexpensive to get a big screen.

The projector function could be developed as an accessory.

6.3.8 Proposal 25 – An operator panel with eye-track and voice or button acknowledgement

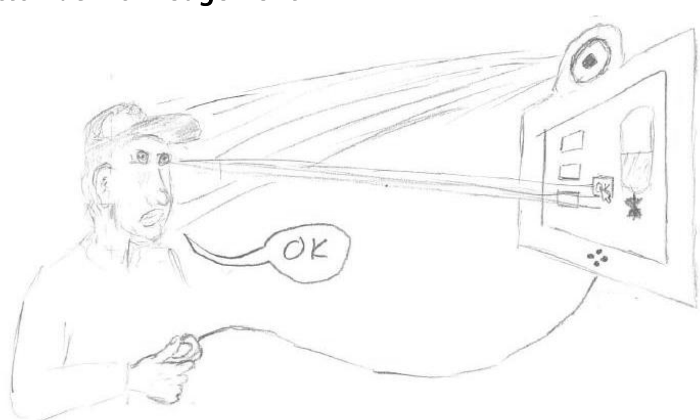


Figure 20 – Sketch of proposal 25

Description:
The display unit is mounted into the wall like the panels of *Beijer Electronics* are today (See figure 3 in *Appendix I*). Above it, in the frame, there's a sensor that perceives the movement of the pupils of the user. The movement of the pupils controls the mouse pointer. To confirm a button push on the display the user presses the button on a handheld remote. Possibly a button push could be confirmed by voice controlling. The voice is perceived by a microphone in the frame.

Advantages:

- The user will only be in contact with handheld remote
- The operator panel can be used ergonomically
- Easy to clean

Disadvantages:

- A new technology that is not reliable
- The air space between the sensor and the user must be free
- Voice controlling does not work in noisy environments
- A microphone causes cavities in the frame
- The “building block” principle is only applied through software

Comments:
The technology is too far away in the future. How will it work if safety goggles are used?

The proposal is to be rejected.

6.3.9 Proposal 26 – Projector remote control

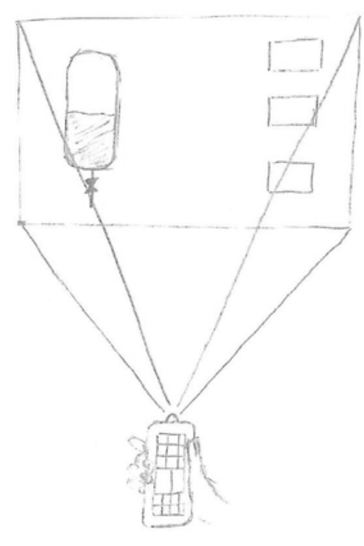


Figure 21 – Sketch of proposal 26

Description:
The remote works both as input unit and a projector. If the electronics is possible to make sufficiently small it could be a part of the remote otherwise it has to be placed separately. The display is projected wherever the user directs the remote, on the floor, the wall or the roof. The mouse pointer is controlled by a touchpad on the remote.

Advantages:
- The user will only be in direct contact with the remote
- The projection is possible to display wherever it is wanted
- The operator panel is possible to use in an ergonomic way

Disadvantages:
- Requires a big empty area available to display the projection
- The air space between the projector and the projection must be free
- The user must hold the hand steady to get a picture of good quality
- New technology that is not reliable
- Maximum HID area is limited (i.e. the "building block" principle is not applied)
- Unsafe with a remote (could be misplaced or cause unwanted inputs)

Comments:
It does not work when the user has unsteady hands. It could be hard to navigate the mouse pointer.

The proposal is to be rejected.

6.3.10 Summary of the third brainstorm

The third brainstorm together with the second one constitutes the foundation of the phase *Selecting Product Concept*. Hence it is not evaluated until beneath the next subtitle.

6.4 Selecting Product Concept

6.4.1 Introduction to concept selection

To advance in the product development project one or several concepts had to be chosen for further development. The decision what concept to choose was made by the project leader and the supervisor of *Beijer Electronics*. To make the decision easier a concept scoring table was made where the different proposals were compared by weighted criteria. The criteria are based upon the tables with needs in *Appendix C.* They were weighted by the project group and the supervisor at *Beijer Electronics* and the concept proposals were rated according to the opinions of the project group.

In the phase *Concept Generation* 26 proposals has been presented. This may seem like there is quite variety of proposals but many of the proposals that have been presented were similar, though, with only small differences. Thus the proposals could be grouped into three branches with internal resemblance. Some proposals did not resemble each other at all and are not considered to be a part of any concept group.

The first proposals that are considered to be similar are 11, 12 and 13. What is common among them is that they are module based and that the building blocks are docked to a base unit consisting of the display and the CPU.

The second grouping is also based on modules. The building blocks are placed in a frame in an optional constellation. The frame has a glass window that covers all the components. The proposals with these similarities are 14 and 15.

The third concept group with an internal resemblance is not module based like the other two. In this case the idea partly is lent from touchscreen cell phones. The significant feature is that there is only one display that both visualizes the process and handles all input. The input is done through touchscreen technology. The proposals with this resemblance are 18, 19, 20, 21 and 22.

The proposals that were rejected in an early state by the supervisors are not included in the phase *Concept Selection* but are still mentioned in *Appendix A*. The proposals of brainstorm three that are claimed to be rejected in the *Comments* sections are still evaluated. Why they are claimed to be rejected is because the statements in the *Comments* sections actually are made after the evaluation.

Detached proposals:
The proposals are 23, 24, 25 and 26.

Rejected proposals:
Proposals 1-10 are rejected but some of them worked as inspirations for later proposals. To make the concept scoring table more comprehensible the proposals that worked as inspirations have been removed and not put into the table.

Proposal 16 and 17 were also rejected and not put into the table.

6.4.2 Concept evaluation

The concept evaluation was done with a concept scoring table according to the method of Ulrich and Eppinger. The table, criteria weighting and criteria explanation and motive are displayed in *Appendix D*.

6.4.3 Results

According to the concept scoring table the best four concepts are as follows:

1. Proposal 14 - All building blocks in the same cover behind a glass window

2. Proposal 15 – All building blocks in the same cover with removable front

3. Proposal 13 – Display unit with dockable HID units

4. Proposal 18 – iTerm

The three first proposals are included among the concepts that were presented to the supervisors of *Beijer Electronics* already after the second brainstorm. The more innovative proposals have gotten significantly worse results. The only one among the new proposals that could compete with the two dominating concepts is proposal 18 (iTerm).

6.5 Selected Concepts

In a meeting with the supervisors and the project leader the concepts were presented from brainstorm three. The evaluation was described briefly and the results were presented.

After some consideration it was decided that concept 13 (*Display unit with dockable HID units*) and 14 (*All building blocks in the same cover behind a glass window*) should be developed further. The reason that two concepts were chosen instead of one was that the supervisor and the project leader thought it was unnecessary to limit the project to one. They both thought the chosen concepts were interesting and wanted to see what the different concepts could lead to. This decision marked the end of the phase *Concept Development*.

7 Concept Designs

In this chapter the chosen concepts are explained more in detail through 3D models.

7.1 Concept 14

The basic idea with the concept was to place the display and HID units behind a glass window. At first it was planned how the customers' requirements of different sizes of displays and input surfaces (HIDs) could be fulfilled.

The frame should be made in three sizes so that the display and HID units could be placed according to Figure 22.

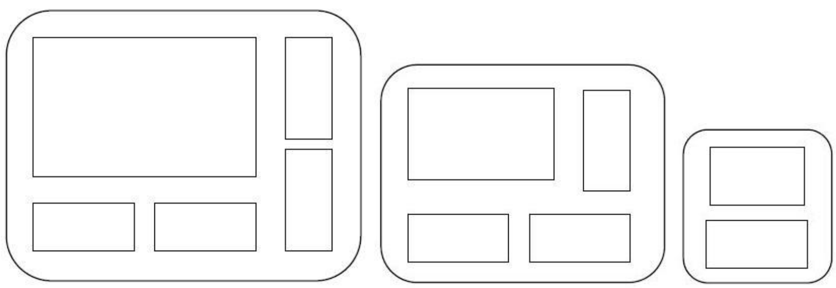


Figure 22 - Concept 14 in the planned sizes.

The idea was that it should be possible to choose different display sizes within a certain frame size. This could be possible if the fixture that fixes the display and the HID units is adaptable. It is adaptable in the way that there is a possibility to break off parts so that there is more room for the display.

The design in *Pro/ENGINEER* is not adaptable for different display sizes, though. The reason for this is that the project team believes it is hard to motivate why a customer would want a smaller display just to get less utilized space. This could only be motivated if the cost difference of different display sizes is sufficiently large. There must be a unique fixture for each of the three frame sizes. The concept and its composition of parts are shown in Figure 23 and Figure 24.

Figure 23 – Concept 14.

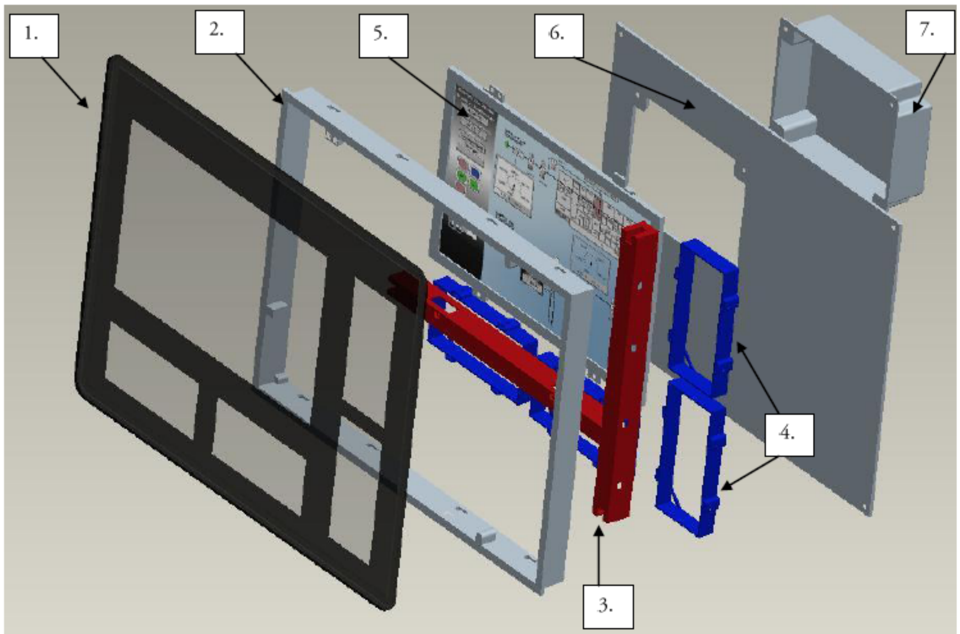


Figure 24 - Exploded view of concept 14 (1.Window, 2.Frame, 3.Fixture, 4.HID frame, 5.Display, 6.Back plate, 7.Electronics casing) Note that the HIDs not are viewed in this figure.

7.1.1 Mounting and details

The first step of the mounting process is to place screws with square shaped heads in holds in the frame (See marking 1 in Figure 25) and the fixture (See marking 1 in Figure 26). The screws are then fastened with nuts. The reason for using the holds with the special screws is to facilitate the mounting, i.e. to be able to mount the components only from one side of the frame after the glass window is glued on.

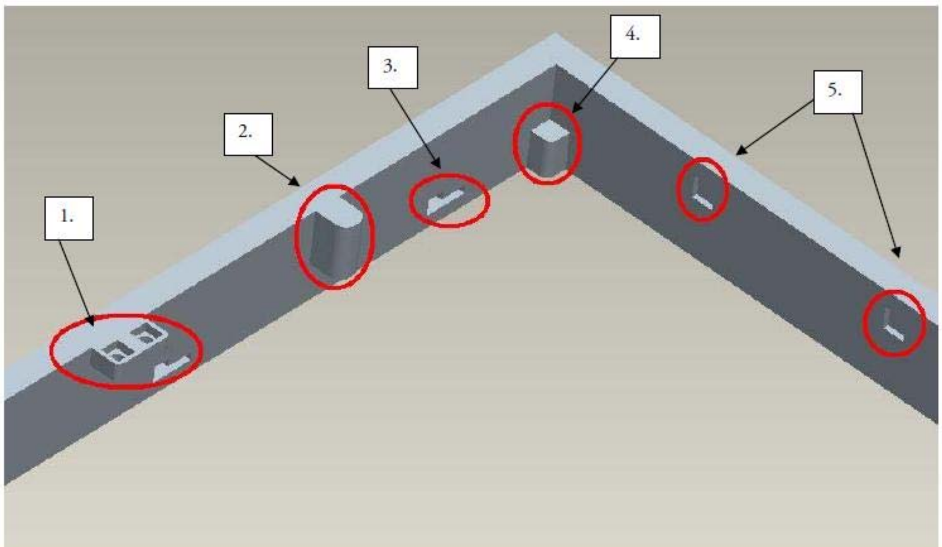


Figure 25 - Details of the frame in concept 14.

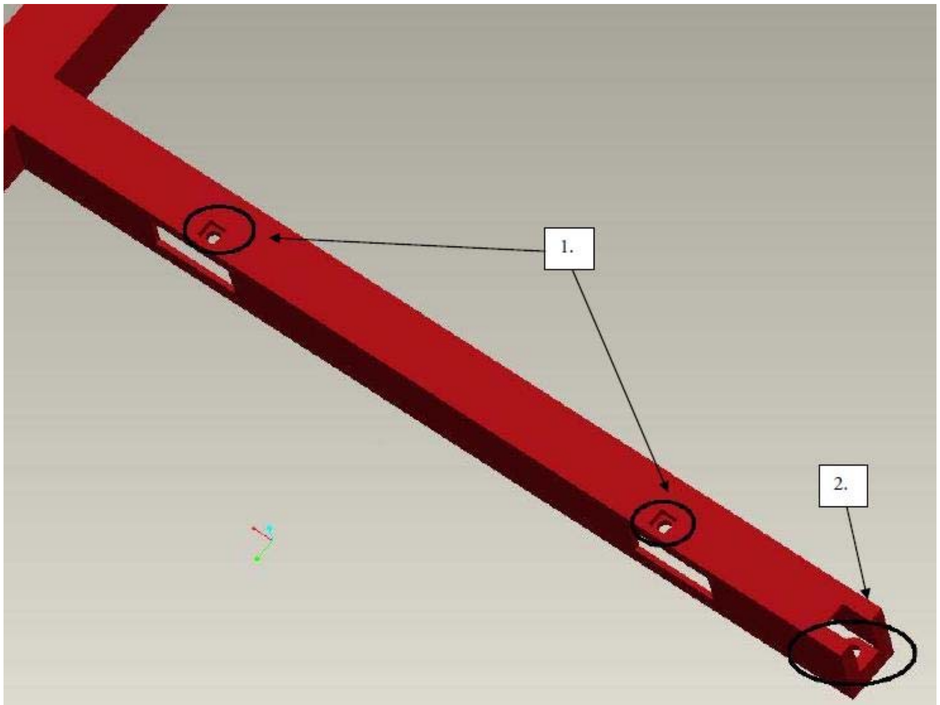


Figure 26 - Details of the fixture in concept 14.

The next step is to glue the glass window onto the frame on the intended ledge. The glass window is the only thing that should be outside the wall after the mounting. The glass window makes the panel isolated against the surrounding environment through a rubber strip that is pressed against the mounting wall.

When the panel is fastened into the wall, forces will act to separate the glass from the frame. Therefore a calculation was done to guarantee that there's industrial glue that holds (See *Appendix B*).

When the glass window is glued the fixture should be mounted. It is fastened with screws through three holds (See marking 2 in Figure 25 and marking 2 in Figure 26).

When the fixture is in place it is time to mount the display to the holds with the square headed screws. The assembler only needs to loosen the nuts, place the display in its holds and then fasten the nuts again. In total the display is fixed with six square headed screws, four in the frame and two in the fixture.

The HID fixture including the HIDs is now to be mounted into the frame and the fixture. The HID fixtures should be snapped onto their places between the frame and the fixture with the snap-ons. In Figure 25 (See marking 5) are the holes for the snap-ons located. Figure 27 shows the frame with mounted fixture, display, HIDs and HID fixtures.

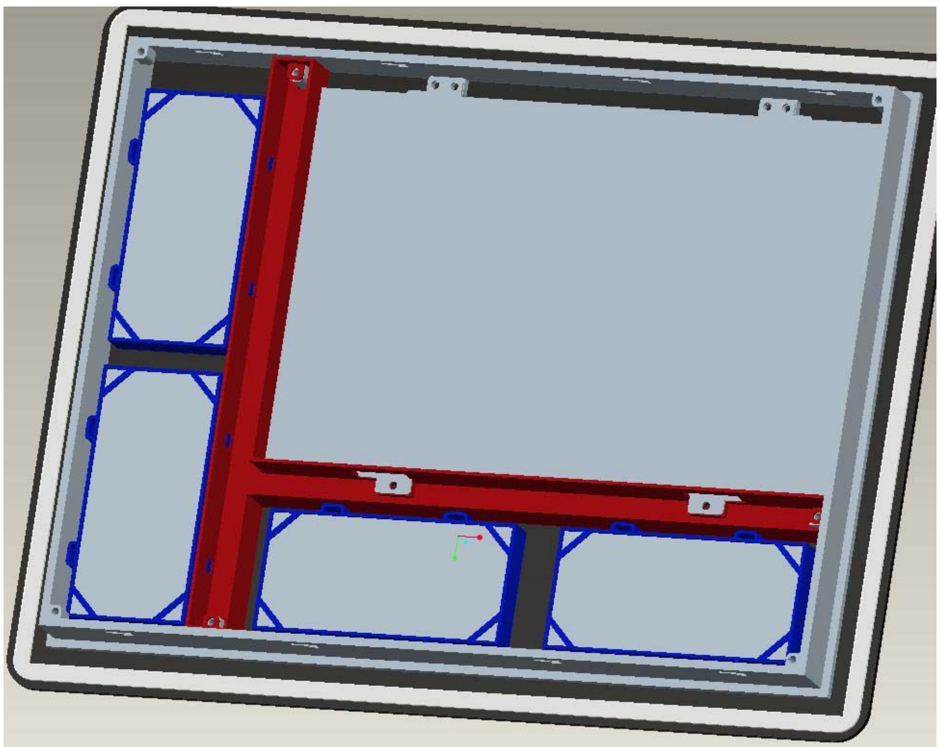


Figure 27 - Mounted components in concept 14.

When all the HID units are placed according to the preferences of the customer, the electronics casing is fastened together with the back plate with four screws and nuts. After that, the back plate is fastened through the threaded holes in the four corners of the frame (See marking 4 in Figure 25). The electronics casing is very simplified in the CAD design. The appearance will maybe change depending on how the electronics inside the casing are shaped. There will also be holes for communication outlets and ventilation.

The panel is delivered already assembled to the customers. To mount the panel a rectangular hole is cut in the wall were the mounting is supposed to be done. The panel is then fastened onto the wall with the same screw devices as is used in the *EXTER* series

(See figure 3 in *Appendix I*). The special holes used for the screw devices are shown in Figure 25(See marking 3).

7.1.2 Dimensions

The model drawn in *Pro/ENGINEER* is the one adapted to the largest display size possible. The dimensions of the model are defined after the dimensions of the widescreen display and HID area needed. The outer dimensions of the widescreen display are taken from datasheets from one of *Beijer Electronics*' suppliers *Toshiba Matsushita*. The HID unit's dimensions (7x15cm) were decided together with the supervisor Robert Nordström and chosen as reasonable dimensions. The depth of the HID units were not decided in advance but set in the CAD model to 1,8 cm. The thicknesses of the back plate, the frame, the window, the HID fixture and the fixture has been set to reasonable values according to the project group. If the concept 14 should be size optimized it is mainly the distance between the HID units and the display that could be decreased. This is done the simplest way by decreasing the dimensions of the fixture. However, it should be done carefully so that the functionality of the fixture is not jeopardized. (TYPE COLOR TFT-LCD MODULE 2007)

Outer dimensions: 54(b) x 42(h) x 9,3(d) cm
Dimensions of the frame: 48(b) x 36(h) x 3.5(d) cm
The weight of the concept 14 is presented in *Appendix F*

7.2 Concept 13

A more detailed drawing was done of concept 13 in *Pro/ENGINEER* on the basis of the handmade sketch that was presented to the supervisors and the project leader. The whole concept assembly and the separate parts are shown in Figure 28 and Figure 29. The frame around the display was meant to be made in as many sizes as sizes of displays. The frame that is adapted to a widescreen 15 "display was drawn in *Pro/ENGINEER*. The principle is the same for the other sizes. Four HID units could be mounted onto the frame. The HID units and their docking stations are of the same size irrespective of display size. The concept 13 is adapted to several possible customer accessories as e.g. a remote control or a protective lid (See chapter 6.2.3). The only accessory that is demonstrated in the CAD design is the remote control (See marking 5 and 6 in Figure 29.

Figure 28 – Front of concept 13. Note that the HID unit does not protrude from the display unit even though it may look like it.

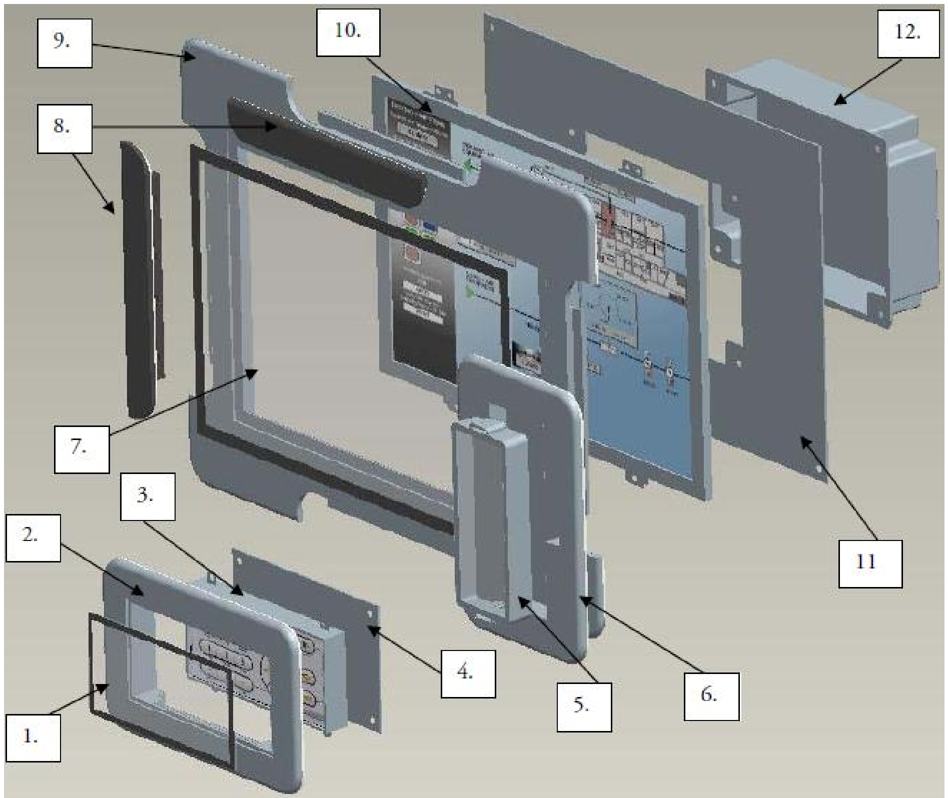


Figure 29 - Exploded view of concept 13. (1.HID Window, 2.HID Frame, 3.HID Fixture, 4.HID Back plate, 5.Remote Holder, 6.Remote Frame, 7.Window, 8.Dummy, 9.Frame, 10.Display, 11.Back plate, 12.Electronics casing)

7.2.1 Mounting and details

The panel window is glued onto the frame from the front (See marking 7 in Figure 29). Then the display is put into the frame from the back and is fastened with 6 screws. There are four holds with threaded holes were the display is fastened (See marking 1 in Figure 30). The electronics casing and the back plate are screwed together before the back plate is fastened onto the back of the frame. The back plate is fastened with screws in four threaded holes in the corners of the frame (See marking 2 in Figure 30). Then the whole frame is mounted onto the wall from the outside and fastened through the screw devices (See figure 3 in *Appendix I*) on the frame from the backside of the wall (holes for screw devices are shown in Figure 30, marking 3). On the backside of the ledge of the frame there is a rubber strip that isolates between the ledge and the wall (See marking 4 in Figure 30).

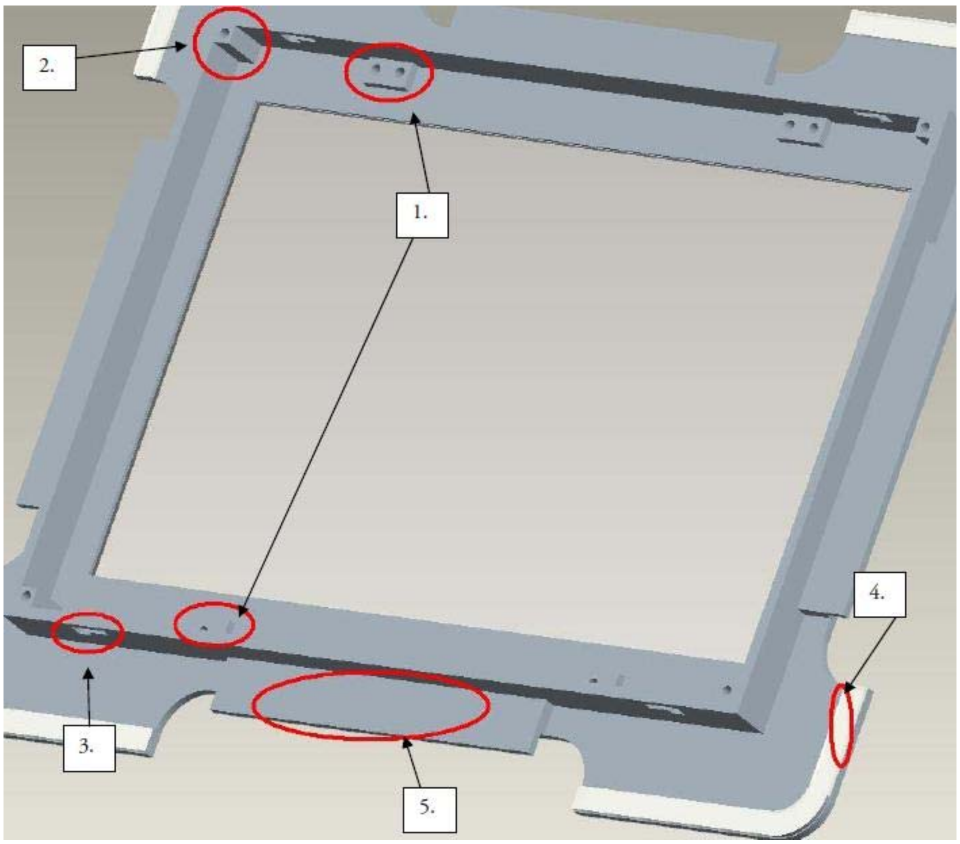


Figure 30 - Details of the frame in concept 13.

The HID windows are glued onto the HID frames from the front by the same principle as the window of the display unit is. The HID unit is mounted into a plastic frame (See marking 3 in Figure 29) which is fastened, with screws on four threaded holes in holds in the HID frame, from the back (See marking 1 in Figure 31). The back plate of the HID frame is fastened on the backside (See marking 2 in Figure 31) by the same principle as the display unit is. At the end the HID frames are fastened onto the wall from the front. The rubber strip on the HID frame (See marking 3 in Figure 31) has to be in contact with the wall and the ledge of the display unit (See marking 5 in Figure 30). The HID frame is fastened by the same screw devices as the display unit (See figure 3 in *Appendix*

I) is. The screws will be fastened against the wall with the ledge of the display unit as withstand (holes for the screw devices are shown in Figure 31, marking 4).

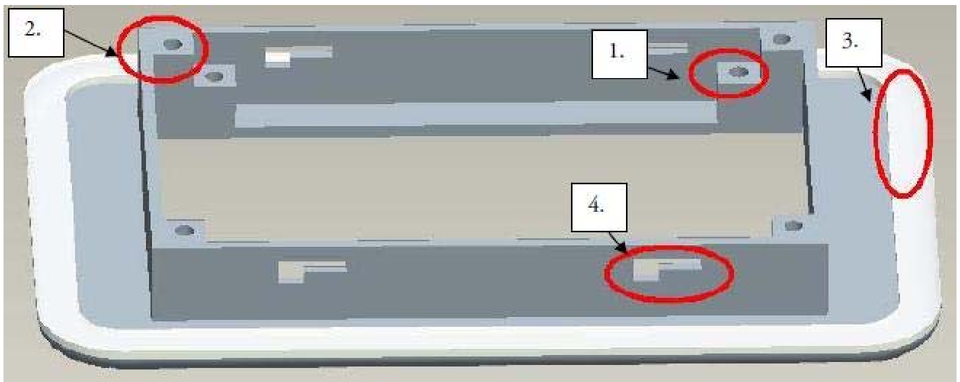


Figure 31 - Details of the HID frame in concept 13.

Dummies (See marking 8 in Figure 29) are fastened to the display unit when no HID units or other accessories are used. The same principle as for the HID frame is used when fastening the dummy. The dummy should be fastened into place between the wall and the ledge of the display unit by the earlier shown screw devices and the holes that are shown in Figure 32.

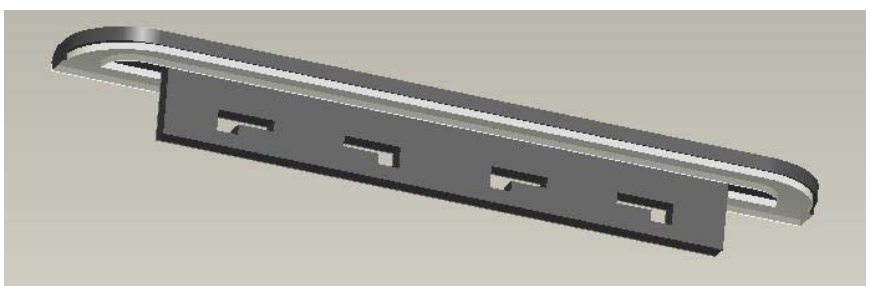


Figure 32 - Dummy in concept 13.

7.2.2 Dimensions

An important property of concept 13 is that it is designed to just take up as little space as called for. Therefore the dimensions are as small as possible without disrupting the functionality and the frame is sized just to hold the display. The width of the edges is sized so that a rubber strip can run along the ledges except where the docking stations are placed. The HID frames are sized to fit into the docking stations. It is important to note that the HID unit does not protrude in relation to the display unit. The HID displays are 15x7cm due to the same reasons that are stated in concept 14. The rest of the dimensions are given reasonable values according to the project group.

Outer dimensions:
45,6(b) x 35,0(h) x 7,6(d) cm (display unit)
21,4(b) x 13,4(h) x 2.5(d) cm (HID unit)
The weight of the concept 13 is presented in *Appendix E*

7.3 Concept 27

This concept arose when it was discussed within the project group in what way the docking in concept 13 should be done. It was suggested that the HID units should not be docked at all but instead mounted with screws onto the wall separately. On the other hand, it is possible to mount the HID units so close to the display unit so that they appear to be docked. The HID units are mounted without having to cut holes in the wall. Instead they are fastened with screws from the backside of the wall. The principle is based on that the HID units can be made thin because all of their electronics ends up outside the wall. If it is not possible to make them thin enough they will protrude quite a lot from the wall and the proposal will then be hard to realize. The proposal was considered to be that interesting, that it was made a whole new concept called concept proposal 27. The whole concept assembly and the separated parts are shown in Figure 33 and Figure 34.

Figure 33 – Front of concept 27

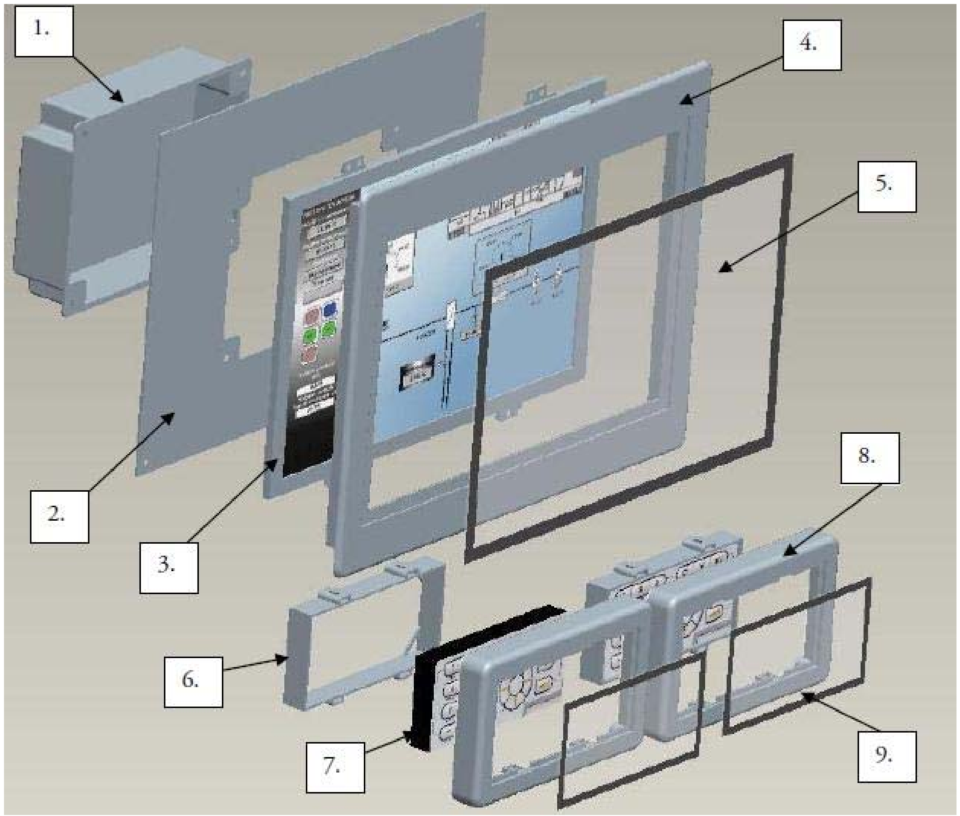


Figure 34 - Exploded view of concept 27. (1.Electronics casing, 2.Back plate, 3.Display, 4.Frame, 5.Window, 6.HID Fixture, 7.HID, 8.HID frame, 9.HID window)

7.3.1 Mounting and details

The display unit (See marking 1-5 in Figure 34) is, as said, designed in the same way as the display unit of concept 13 except that it does not have docking stations. Hence, only a rectangular hole has to be cut in the wall where the display unit is mounted with the earlier mentioned screw devices (See figure 3 in *Appendix I*). The mounting of the display, back plate and electronics casing is exactly the same as in concept 13 and therefore are no further details described.

The HID units (See marking 6-9 in Figure 34) are similar to the ones as in concept 13. The HID display is placed in the HID fixture (See marking 6 in Figure 34). The HID fixture is fastened in the HID frame by snap-on holdings (See marking 1 in Figure 35). Where the HID units should be mounted, four holes must be drilled for screws and one larger where a USB chord is to be drawn. The screws are screwed from the backside of the wall and are fastened through threaded holes in the HID frame (See marking 2 in Figure 35). Along the ledge of the HID frame, that makes contact with the wall, a rubber strip (See marking 3 in Figure 35) runs to isolate from the surrounding environment. In that way no back plate is needed because the wall itself covers the back of the HID unit.

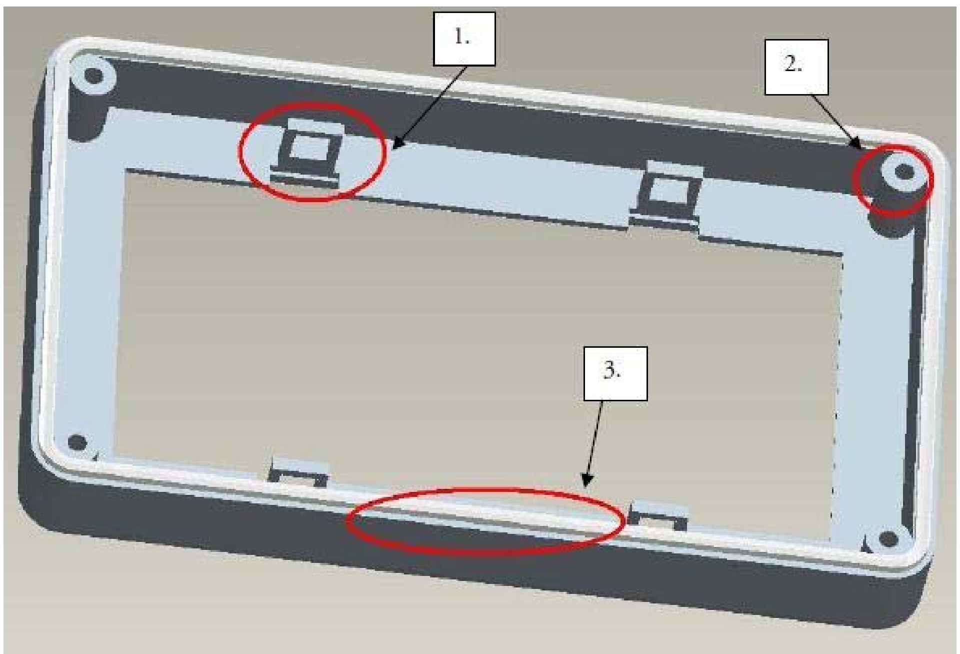


Figure 35 - Details of the HID frame in concept 27.

7.3.2 Dimensions

The dimensions of concept 27 are a little bit smaller than concept 13's. The biggest difference is that the HID units protrude from the wall a bit more. Furthermore a part of concept 13's HID units merge with its display unit's front while the HID units of concept 27 are completely separate.

Outer dimensions:
40 (b) x 30(h) x 7,6(d) cm (display unit)
19,4(b) x 11,4(h) x 2,3(d) cm (HID unit)
The weight of the concept 27 is presented in *Appendix E*

8 Manufacturing Methods and Material Selection

Due to the similarities in many details of the concept proposals and the details of the *EXTER* series it is possible to use the same manufacturing methods and material selection. These materials could be considered suiting because they have been used in functioning products for several years. That is why there are only a few researches done about manufacturing methods and materials for details that already exist in the *EXTER* series. If a research is done still, it is because there is reason to believe it is possible to find a more suitable method or material. For the parts of the concepts that are completely new manufacturing method and material selection will be presented.

8.1 Concept 14

8.1.1 Panel window

In this concept the panel window is significantly larger than in the *EXTER* series and serves as a front for the panel. The panel window is considered to be a new detail and therefore the material selection is presented. Manufacturing method is not necessary to be presented because the panel window is assumed to be supplied already made from the manufacturer.

While choosing appropriate material for the window from the material database program CES the two most important properties that were considered were transparency and permittivity. That the window must be transparent is quite obvious because it must be possible to see the display from the outside as if the window would not have been there. Permittivity is a property that is the measurement of a material’s ability to transmit (permit) an electric field. This is important because there is going to be a capacitive film on the backside of the window that detects touch through electric fields. Other properties that also were taken into account in the choosing process were weight, hardness and price. The weight was calculated with the dimensions from the *Pro/ENGINEER* sketches and the densities from CES. Some materials with these properties were gathered in table 1 in *Appendix E* and made up the basis for what material to choose.

As displayed in the table the permittivity and hardness of Soda-Lime glass are much higher than of the other materials. It is quite heavy though but the positive arguments are quite dominant and therefore Soda-lime glass is chosen.

8.1.2 Frame

In the *EXTER* series a casted aluminium frame is used. Whether or not the frame is to be casted in concept 14 does not need to be discussed, according to the project group, because its shape and wealth of details require it. Because the frame constitutes a big part of the volume and weight of the panel a research was done about material selection.

Following criteria were considered to be the most important by the project group and the supervisor at *Beijer Electronics*.

The material should:

- be reasonable in price (aluminium was used as reference)
- be of light weight
- be a metal (To give an impression of a premium product)
- be easy to cast
- be a good electrical conductor (the better conductivity the better electromagnetic screening)
- be environmental friendly

The material database CES was used in the research to get some possible candidates. figure 1 in *Appendix E* shows the price of the material in relation to the density of a number of metals. The most feasible candidates to exchange aluminium alloy with, as the material, are magnesium and zinc alloys. The differences in raw material price and density are quite big in favour for aluminium. Tooling cost when die casting zinc, magnesium and aluminium are considered to be similar after consulting experts at LTH[12] and does therefore not make a difference.

Figure 2 in *Appendix E* shows electric conductivity in relation to the castability. All the metals in the diagram have a good electric conductivity. There are some metals that has better castability than aluminium alloys for example zinc alloys and cast iron, but a better castability does not make up for a higher density which is considered to be a more important criterion by the project group.

According to CES all metals shown in figure 3 in *Appendix E* are recyclable. Figure 3 in *Appendix E* shows embodied energy in relation to CO_2 footprint (primary production). Aluminium alloys are relatively high both when it comes to their energy consumption and their CO_2 footprint. Here it is significant to know how important environmental

[12]Andersson, Carin and Kirkhorn, Lanny, TeknD universitetslektor, CI forskningsingenjör, respectively, personal conversation 9/2-2009

friendliness is in relation to function and cost. Zinc has for instance good environmental properties but is unreasonably heavy. (Granta, CES EduPack 2008)

Because the frame is not exposed to any great forces the strength properties are not considered in the comparison as long as the frame is made of metal.

With the following researches of criteria the conclusion that aluminium should be used in the frame is made, mostly due to price and density.

8.1.3 Electronics casing

For the electronics casing the same material and manufacturing method as for the frame are used.

8.1.4 Fixture

The fixture is a new detail in the concept and therefore both manufacturing method and material selection needs to be researched. The fixture fixes the display and the HID units and is not affected by any great force. The cross-section of the fixture has not got the best shape to achieve stability which calls for higher demands that the material is rigid enough. It could be plausible to minimize the size of the fixture in a size optimization of the concept, though. In that case it calls for even higher demands on the rigidness of the fixture.

The fixture needs to be casted because it is rich in details. It needs to get finish treatments like drilling and threading of holes etc. The fixture does not need a painting, though, because it is going to be placed inside the panel. Because there are already parts of the design that weighs a lot it is desirable that the fixture is made of a light material.

The following criteria for the material were used in the research. The criteria were the ones considered to be the most suitable by the project group.

The material of the fixture should:

- be rigid
- be light
- be easy and cheap to manufacture
- be environment friendly
- handle temperatures generated in electronic equipment

The most suiting materials are listed in table 2 in *Appendix E*.

Regarding the rigidness, the fixture can achieve better characteristics if the wall thickness is increased. If plastic is used the stability is easy increased by making smaller design changes like adding latches. Table 2 (See *Appendix E*) shows that the metals have much greater Young's modulus than the plastics. Magnesium has a little bit lower Young's modulus than the other metals but is still much better than the plastics. The Young's modulus for the plastic material POM is assumed to be sufficient for a good functionality because it is used in a wide range of applications where stiffness is required. The conclusion, when considering rigidness, is that the fixture could be made in both metal and POM but if the plastic is chosen should some small design changes be made. (Granta, CES EduPack 2008)

The weight has been calculated with the density of the material (See table 2 *Appendix E*) and the volume of the fixture from the *Pro/ENGINEER* models. The volume of the fixture is $1.1316e^{-4}$ m^3 and this result in a weight interval of 0,283-0,328 kg for aluminium. If the fixture is made of the plastic POM the interval is 0,157-0.162 kg. The smaller weight of the plastic alternative is not enough as an argument because still both of the alternatives have a relatively small weight.

As table 2 (*Appendix E*) shows the castability is good for the metal alternatives. The plastic POM has a low castability but a higher moldability.

It is difficult to determine if the fixture should be manufactured in a metal or a plastic material due to price. The prices in table 2 (*Appendix E*) are only raw material prices, which varies a lot over time (according to a manufacturing methods expert at LTH[13]), and should not determine the material selection. Another cost related to material is the price of the manufacturing tool. When it comes the tool cost it is depending on supplier and hard to establish according to a manufacturing methods expert at LTH (Andersson). The manufacturing methods expert at LTH (Andersson) finally claimed, though, that the fixture would be easier to manufacture and have a lower tool cost if it is moulded in a plastic material compared to die-casted in aluminium.

According to CES all the materials in figure 4 (See *Appendix E*) are recyclable. Diagram 4 (*Appendix E*) shows embodied energy in relation to of CO_2 footprint (primary production). In the diagram it is possible to see that the properties could not be separated as plastic and metal properties. The best materials according to the environmental properties are the plastics and the zinc alloys. However, the question is how much the environmental aspect should be considered and if it could make up for the functional

[13] Mats Andersson, TeknD, university lecturer, Department of Production and Materials Engineering. Personal conversation 31/10-08

criteria. In the end the project group considered it not to be a decisive criterion at least. (Granta, CES EduPack 2008)

The presented operator panel concepts are not equipped with details such as ventilation. Even if an operator panel has good ventilation the heat generated from e.g. the CPU and display increases the temperature above room temperature. If the fixture expands due to increased temperature the functionality is jeopardized. Plastic materials have higher thermal expansion coefficients than metals. According to CES the plastic POM has a maximum service temperature 76,9-96,9 ^{o}C. The maximum service temperature is defined as the highest temperature at which the material can reasonably be used without oxidation, chemical change or excessive deflection ("creep") becoming a problem. The assumption that the temperature never reaches 70 ^{o}C was made by the project group and therefore the plastic material POM could be used. Metals have higher maximum service temperatures than plastics. (Granta, CES EduPack 2008)

In conclusion the plastic POM was the best choice of material for the fixture. The metal that best fulfils the criteria for the fixture was aluminium. There was one important factor that motivates the choice of POM before aluminium, and that is the moulding tool cost. To summarize POM is a light plastic material, sufficiently rigid, environment friendly and cheap in raw material, production and moulding.

8.1.5 HID fixture

The HID fixture is a new detail in the concept but it is very similar to the plastic frames that are used in the *EXTER* series to fix displays. Therefore it is suitable that it is casted in the same way as the fixture and in the same plastic, POM.

The idea with the snap-ons on the HID fixture was also borrowed from the plastic frames of the *EXTER* series. Therefore again it is suitable to use the same plastic to achieve the same elasticity with the snap-ons.

8.1.6 Back plate

The back plate is an existing part of the *EXTER* series but in the same way as the frame it constitutes a big part of the volume and weigh about 1,65kg in aluminium (calculated with the volume from the *Pro/ENGINEER* model). Therefore a research was done whether or not there is a more suitable material. Materialwise almost the same criteria are used as for the frame and the electronics casing because the project group found them suiting. The only difference is that the plate should not be casted. The back plate can be bought ready-made with only the finishing treatment to be done.

According to figure 4 in *Appendix E* you can get a more environment friendly back plate by using zinc alloys instead of aluminium. This gives less energy consumption and CO_2 footprint (primary production). Changing to zinc from aluminium creates a big change in density and result in a weight of about 3,5kg (calculated with the volume from *Pro/ENGINEER* model). This weight increase makes it unreasonable to change material to zinc according to the project group.

The conclusion is that the best alternative for the back plate is aluminium sheet.

8.2 Concept 13

In the following sections manufacturing methods and material selection for details that are different from concept 14 are presented.

8.2.1 Panel window

The panel window that is used for this concept is much smaller than in proposal 14. This weakens the argument to use a plastic window to get a lower weight according to the project group. As shown in table 1 (*Appendix E*) the hardness and permittivity is much better for glass compared to plastics.

In conclusion Soda-lime glass is the best choice.

8.2.2 HID frame

It is suitable to cast the detail because of its richness in details.

Materialwise this detail should be made of aluminium according to the same arguments as for the frame in proposal 14.

8.2.3 HID back plate

This detail should be of the same material and be manufactured in the same way as the back plate of the frame because of its almost identical appearance.

8.2.4 Dummy

The dummy should be fastened both onto the wall and onto the panel, which requires that the material should hold for some forces. Then the dummies also must blend in with the rest of the panel to get a uniform appearance. To keep the feeling of quality and fulfil the above-mentioned criteria the dummies should be made of metal and then aluminium could be used to get a uniform material for the front.

The dummy should be casted because of its shape.

8.3 Concept 27

All the details from the concept 13 are also used in this concept besides the back plate for the HID unit. Therefore the same materials and manufacturing methods are used in this concept.

9 A Basis for a Future HID Prototype

This part of the Master Thesis presents the result of the work with making a basis for a future input unit (HID) prototype. The presented work will hopefully assist *Beijer Electronics* when making a prototype of a HID unit. As mentioned in chapter 1 the objective of the HID design changed drastically during the project. Before the changes, the plan was to develop a functional prototype of a HID unit.

The project group thought that the best way of drawing up guidelines on how to make a HID PCB is simply by presenting the work with the prototype that was done before the objective change and the recommendations it was designed after. The theory behind the used touch sensing technology is presented in chapter 9.2. More practical studies and theory about tuning a HID prototype and USB communication between an input unit and a host computer are presented in chapter 9.3 and 9.4.

9.1 HID Design

9.1.1 Development of a prototype HID unit

The HID is a part of all the generated concepts. Below a specification of the requirements for the prototype is presented. They were put together by Robert Nordström and the project group.

HID specification

- The HID should consist of a touchpad
- A touch area of 15x7 cm is needed
- The area should be configurable through software
- The touch area should be made on a circuit board with a copper pattern
- A microprocessor is going to be used for the control of the HID
- The HID should work as a mouse when connected to a PC through USB
- The HID should be able to detect more than two fingers simultaneously (multitouch)

Research and preparations

Before the design of a prototype HID was started some preparations had to be made. Some research on the touch technology was done and the result is presented as guidelines on how to make a HID (See chapter 9.1.2-9.1.3) and a theory description (See chapter 9.2).

Some practical experiments were made with two Cypress evaluation kits supplied by *Beijer Electronics*. The objective of the experiments was to gain experience with capacitance touch technology and the software (*PSoC Designer 5.0*[14]) used for programming a microprocessor supporting touch technology. These experiments are presented in chapter 9.3.3 and 9.4.3.

Development

The first step was to find a microprocessor that could be used for the prototype development. A few microprocessors from different companies were considered. Finally the project group chose the CY8CTMA120 *PSoC* device from Cypress Semiconductor Corporation. The reason for choosing this microprocessor was that it is from the same manufacturer as the evaluation kits available and thereby the same software can be used as in the experiments. Another advantage of choosing a microprocessor from Cypress Semiconductor Corporation is that they have a lot of documentation on their technology.

To develop the CAD schematics and PCB prints for the prototype the *CADSTAR* PCB design program was used because this is the PCB software used by *Beijer Electronics*.

Which components were needed, for the PCB, was figured out by reading the datasheet for the *PSoC* device and looking on schematics from the evaluation kits.

9.1.2 Schematic

The PCB schematic is presented in figure 5 in *Appendix G*. The main function of the circuit is to read the sensors and send the information to a PC through a USB connection. The *PSoC* device is going to scan the sensors with Cypress' CSD method (explained in chapter 9.2.1). Why the CSD method is chosen and not another is because it is recommended when a thick overlay is used. (Lee 2007a, p. 2)

The microprocessor is programmed by a *Cypress* device named *PSoC miniprog*, which is connected to a 5 pin header (See figure 5 in *Appendix G*). While programming the microprocessor, the board is powered by the *miniprog*. When the prototype is connected to a PC the board is powered through the USB connection. The supply voltage from the power sources is bypassed to ground with a 0.1μF capacitor to avoid transients as it is recommended by Cypress Semiconductor Corporation. (True Touch™ Multi-Touch All-point Touchscreen Controller 2008, p. 8)

[14] PSoC Designer is software for programming Cypress' PSoC applications developed by Cypress Semiconductors Corporation. (PSoC Designer(TM) 5.0 – Software and Drivers 2008)

Cypress recommends placing 300Ω resistors in series on communication lines to increase the RF immunity of the system. This should dampen the resonance of each trace. The resistance should be placed as close to the *PSoC* device as possible. By the same reason it is also recommended placing 500 Ω resistors in series on the sensor lines. Because of these recommendations 330 Ω resistors are placed on the communication lines, from the USB and the 5 pin header, and 560 Ω resistors are placed at each input trace in the presented schematic (See figure 5 in *Appendix H*). (Lee 2008a, p. 3)

The CSD algorithm requires two external components, R_b and C_{MOD} (described in chapter 9.2.1). The resistor and capacitor are connected to the upper side of the *PSoC* device. According to Cypress a C_{MOD} value of 3.9 nF is recommended. $R_{b,}$ which require some later tuning for proper performance, have the recommended value of 5-10kΩ. The chosen components are a capacitance of 3.9nF and a resistor of 5kΩ. The tuning process for R_b is described in chapter 9.3. (Lee 2007a, p. 3)

Note that the other *PSoC* devices, than the used one, have special pins (modulator capacitor pin and feedback resistor pin) where the C_{mod} and R_b have to be placed. The *PSoC* device that will be used to the prototype have no guidelines about the modulator capacitor pin and feedback resistor pin, thus the components were placed on two random unoccupied I/O pins. (Tsui 2007, p. 7)

Two slider segments (explained in chapter 9.2.2) with 18 and 9 slider elements were used for detecting the x and y coordinates, respectively. The horizontal sensor pattern with 18 slider elements was connected to the *PSoC* by using diplexing (explained in chapter 9.2.5). The reason for using diplexing was that the latest version of *PSoC* did not support more than a certain amount of slider elements when using the CSD algorithm. As seen in the schematics (see figure 5 in *Appendix G*) nine 0 Ω resistors have been added to the design. This is a safety measure to avoid total disaster if the diplexing does not work as planned. The idea was to get the left part of the sensor area to work without diplexing and later try diplexing by adding the resistors.

9.1.3 Guidelines for a HID PCB layout

These guidelines were followed when making the PCB for the prototype. The information is taken from *Cypress Semiconductor Corporation's* homepage and some statements are assumptions by the project group and the supervisor and co-supervisor of *Beijer Electronics*. The SNR is a very important consideration when making the layout. Cypress recommends a minimum SNR of 5:1 for *CapSense* buttons. This requirement is specified so that the *PSoC* can discriminate between the on and off states for each sensor when noise is present. The SNR could not be measured before the PCB is produced and the components are mounted. Measurements of SNR are described in chapter 9.3.3. By following these guidelines there is a greater possibility to get a better SNR. (Lee 2007a, p. 3)

Sensor pattern
There were a lot of details to consider when choosing a sensor pattern for the prototype. Sensor shape, sensor size and spacing, between sensor and ground, had to be chosen. Each of these parameters affects the sensors' output. How high sensor output that is needed depends on different things, for example thickness of the overlay material.

A single touch element's geometric should not have an angle less than 90° and the recommended shapes are solid round patterns or if that is not possible a square or rectangle. (Lee 2008a, p. 3)

A touchpad consists of two independent sliders (explained in 9.2.3). There is a recommendation from Cypress to use a hexagon shape on the elements when making a touchpad pattern of copper material on a PCB. Another recommended pattern layout is octagon shape. The chosen pattern consists of squares rotated 45° (diamond shape). This diamond shape pattern is not optimal when using copper but still possible to use. The reason for choosing a pattern that is not optimal for the PCB is because a future HID unit would probably be using ITO (deposited Indium Tin Oxide) according to Andreas Sjölin, and the diamond shape is recommended by Cypress when using ITO. (Lee 2008a, p. 7), (Grivna and Berry[15])

The area of a sensor influences the output. Bigger sensors give higher output levels and higher SNR. The upper size limit of a single sensor element is dependent on the contact area of a finger which could be estimated to a circle with a diameter of 10mm. When designing a pattern for a slider, or in this case a touchpad, the upper size limit is smaller. This is because a finger must be in contact with at least two sensor elements to be able to interpolate the finger position, i.e. to get a higher resolution than the amount of sensor elements. (Lee 2008b, p. 3), (TrueTouch Gesture Data Sheet 2008, p. 5)

The clearance between sensor and ground is also a parameter which affects the sensor output level. The sensitivity increases with both button size and clearance. Also in this case a slider needs two elements in contact with the finger to function properly. This is also dimensioning the size of the clearance. Note that oversizing the gap leads to increased crosstalk between buttons. (Lee 2008a, p. 3-5)

[15]Grivna, Edward and Berry, Steven, Sr. Architect MTS and Sr. Product Marketing Manager, respectively, Cypress Semiconductors Corporation, Lecture slides

When using a diamond shape pattern it is recommended to use a spacing of 5-6 mm. The chosen sensor pattern with measures, in the PCB design, is shown in figure 6 in *Appendix G*. However, when the spacing recommendations were applied in the PCB design they were misinterpreted. Instead of spacing the distance between the diamonds´ centres to 5mm, the squares´ spacing was set to 5mm. This resulted in a spacing of 7.07mm that actually exceeded the recommended maximum. This was discovered after that it was decided not to make the HID prototype. Therefore the project group felt that changing the design was unnecessary. The opinion of the project group was that exceeding spacing probably would work anyway, but Cypress' recommendation should still be followed. (TrueTouch Gesture Data Sheet 2008, p. 5)

Traces
Both traces and buttons affect the parasitic capacitance (explained in chapter 9.2.6). Low parasitic capacitance is desired to make the dynamic range of the system as large as possible. Trace capacitance is minimized by using shorter and narrower traces. When making the circuit on PCB it is recommended to use traces with a length less then 300mm. Trace widths of 0.17-0.20mm is recommended for most applications. (Lee 2008a, p. 2)

The trace widths used in the PCB design are between 0.17-0.2mm for sensor traces. Ground and V_{dd} uses a width of 1.016mm (necked 0.508mm).

Traces should not be routed under sensor pads unless the trace is connected to that sensor. Neither should capacitive sensing traces be running close or parallel to high frequency communication lines, such as I2C or SPI master. If it is not possible under any circumstances to avoid crossing sensor traces with communication lines, the intersection should be perpendicular. (Lee 2008a, p. 2)

Board properties

Layer:
According to Cypress a common *CapSense* application consists of a two layer board with sensor pads and a hatched ground plane on the top layer and everything else on the bottom layer. When using this design a board thickness of 0.5-1.6mm can be used. Thinner boards decrease the SNR. (Lee 2008b, p. 3), (Lee 2008a, p. 1-2)
When designing a touchpad you need to have sensor pads on two layers to get proper functionality. (TrueTouch Gesture Data Sheet 2008, p. 1)

The first idea for the HID design was to use a two layer board. This decision got the result that the board size had to be bigger than the sensor pattern because the components had to be placed beside the pattern (See figure 1 in *Appendix G*). Later Robert Nordström questioned the decision to use a two layer board. The argument was that the distance between the sensor layers becomes too big when using a two layer board and this would result in signal processing problems. Instead a four layer 1.6mm board is recommended which gives a smaller distance between the two sensor layers.

Note that if the presented PCB design, in this report, is going to be manufactured it should be changed to a 4 layer board. The size of the board could be minimized to the size of the sensor pattern when using a 4 layer board. Due to the deadline of this Master Thesis changes are not made, thus the 2 layer design is presented (See figure 1-4 in *Appendix G*).

<u>Ground plane:</u>
A ground plane is often used to shield the sensor and sensor traces from noise sources and to control the locations of touch sensitivity. A ground fill is added to both the top and bottom layer. When adding ground fill close to a sensor there is a trade off between noise immunity and maintaining a high level of signal. As mentioned before, the spacing between the button and the ground fill is influencing the parasitic capacitance, C_p. Increasing the clearance around the traces increases the SNR. (Lee 2008b, p. 2-3), (Lee 2008a, p. 3)

A typical hatching for the ground fill is 15% (7mil line, 45mil spacing) on the top layer and 10% (7 mil line, 70 mil spacing) on the bottom layer. The PCB design for the touchpad prototype has a ground filling of 100%, though. This was a recommendation by Andreas Sjölin. (Lee 2008a, p. 3)

<u>Overlay material:</u>
The overlay material is placed over the sensors for protection of the PCB. Both material and thickness of the overlay is very important design parameters that affect the functionality of the design. (Lee 2008a, p. 7)

The dielectric property of the overlay material affects the capacitance, i.e. a high dielectric constant lead to high sensitivity. The higher dielectric constant a material has, the better its ability to transmit electric fields is. Table 1 shows the dielectric constant of some common overlay materials. (Lee 2008a, p. 7)

Material	ε_r
Air	1.0
Formica	4.6–4.9
Glass (Standard)	7.6–8.0
Glass (Ceramic)	6.0
PET Film (Mylar®)	3.2
Polycarbonate (Lexan®)	2.9–3.0
Acrylic (Plexiglass®)	2.8
ABS	2.4–4.1
Wood Table and Desktop	1.2–2.5
Gypsum (Drywall)	2.5–6.0

Table 1 - The dielectric constants of different materials. (Lee 2008a, p. 7)

Sensitivity is inversely proportional to overlay thickness, i.e. thicker material gives lower sensitivity. Signal and noise are lowered when increasing the overlay thickness which results in a lower SNR. (Lee 2008a, p. 8)

In table 2 recommended maximum thickness for different *CapSense* applications are presented for a plastic overlay. A touchpad application is recommended a maximum overlay thickness of 0.5mm for plastic material. By choosing glass as the overlay material the thickness could be made 3 times thicker (calculated with dielectric constants of plastic and glass, 2.5 and 8, respectively). (Lee 2008a, p. 8)

Design Element	ε
Button	<5 mm
Slider	<2 mm
Touchpad	<0.5 mm

Table 2 - Thicknesses for a plastic overlay in different applications. (Lee 2008a, p. 8)

The overlay must be thick enough to prevent dielectric breakdown due to electrostatic voltage. The electrostatic discharge can cause permanent damage to the *PSoC* device. Table 3 shows the minimal overlay thickness for some common overlay materials when handling a voltage of 12kV. The electrostatic voltage on a human body can reach 15kV when the humidity is low. (Lee 2007a, p. 9), (Lee 2008a, p. 8)

Material	Breakdown Voltage [V/mm]	Minimum Overlay Thickness at 12 KV [mm]
Air	1200–2800	10
Glass–Common	7900	1.5
Glass–Borosilicate (Pyrex)	13,000	0.9
Formica	18,000	0.7
ABS	16,000	0.8
Acrylic (Plexiglass®)	13,000	0.9
Polycarbonate (Lexan®)	16,000	0.8
PET Film (Mylar®)	280,000	0.04
Polyimide Film (Kapton®)	290,000	0.04
FR–4	28,000	0.4
Wood–Dry	3900	3

Table 3 - Breakdown voltages and minimum overlay thicknesses of different overlay materials. (Lee 2008a, p. 7)

Overlay adhesive:
It is very important that the overlay material is in contact with the PCB. The sensitivity is drastically decreased when there is an air gap between overlay and PCB because of the low dielectric constant of air. An easy solution for eliminating air gaps is using some kind of adhesive film in the gap. (Lee 2008a, p. 8)

9.2 Touch Sensing Technology and Methods in Theory

Nowadays touch technology is used in many applications around the world. It is used in e.g. touch pads on laptops and home electronics where mechanical buttons used to be. In this project the technology is to be used in the HID unit. The unit will have an area that is sensitive to the proximity of human fingers. The unit will then be able to establish, through sensors, where one or many fingers are located over the area. The theory behind the parts of touch technology that is used in this project is briefly reviewed below.

9.2.1 Touch sensor technology

To achieve the function of an area sensitive to the proximity of fingers capacitive sensors are needed. In this case the copper pads on a printed circuit board are used as sensors. Between a pad connected to a voltage and a surrounding ground an electrical field is generated. The field has a certain capacitance which is increased if a fingered is present. This is due to that the flesh of a human being is able to hold electrical charge. (*CapSense* Sigma-Delta Datasheet 2008, p. 4-6)

To monitor whether or not a finger is present a *PSoC* microprocessor is used. Within and externally of the microprocessor there are several components together capable of producing digital signals based on the measurements of the sensor. The microprocessor can use different methods of monitoring. The one that is used in this case is called CSD (*CapSense* with Sigma-Delta A/D). How it works is displayed in figure 36 below.

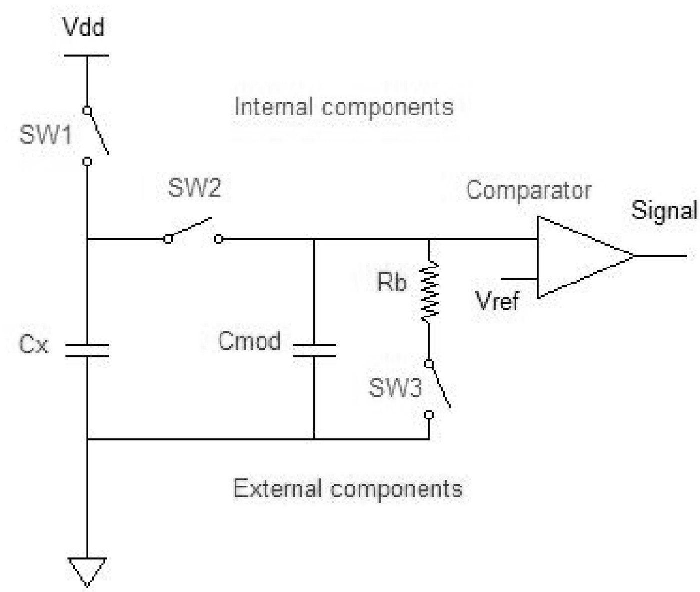


Figure 36 - Configuration of CSD.

C_X represents the capacitance of a sensor. The switches SW_1 and SW_2 together forms an equivalent resistor between V_{DD} and C_{MOD}. When R_B is switched to ground, the voltage on C_{MOD} decreases. When R_B is open, the voltage on C_{MOD} increases. The comparator changes state of the signal based on the voltage on C_{MOD} relative to V_{REF}. When a finger is present, C_X is larger and the equivalent resistor to V_{DD} is smaller, allowing more current to flow into C_{MOD}. Hence the comparator signal will be in a high state longer, and a lesser time in the low state. If the relation of the time in the high state compared to the time in the low state reaches a certain ratio the sensor is considered to be in a finger present state otherwise not. (Lee 2007a, p. 2-3)

9.2.2 Touch slider

A slider detect movement over a pattern of copper pads (sensors) described in chapter 9.2.1. The pads are arranged in a single row (See figure 37). For a microprocessor to be able to calculate the position of a finger at least three sensor pads must be activated. This is due to an algorithm in the programming of the microprocessor that calculates the position of the centre of the finger. Calculating the position with three pads instead of for instance one makes a higher resolution of the position possible. Because of the pads' arrangement it is possible to slide the finger along the pattern so that the slider could function as for instance a volume or a dimmer control. (Lee 2007a, p. 5-6)

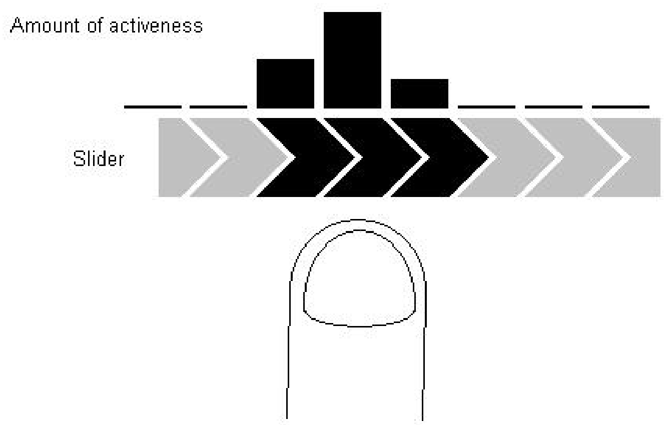


Figure 37 - The activeness of a slider segment.

9.2.3 Touchpad

A touchpad made by the capacitive touch technology of Cypress consists of two sliders. The sliders are arranged in a certain pattern (explained in the next caption 9.2.4) where one of them is horizontally aligned and detects touch in the x direction and the other one vertically aligned and detects touch in the y direction. When knowing the x and y coordinates, the position of the finger touch can be calculated.

9.2.4 Touch area pattern

Copper pad sensors (as described in 9.2.1), arranged in a certain pattern of squares (See figure 38), are used on the area sensitive to the proximity of fingers. This is done according to the recommendations of the microprocessor manufacturer to get an equal distance between the pads and ground all over the pattern. The pattern is arranged in horizontal and vertical groups of pads. Each group is connected and together forms one sensor.

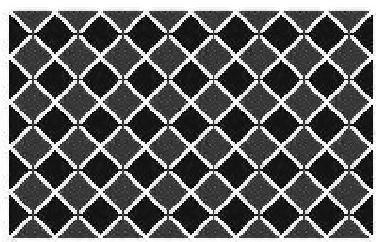


Figure 38 - Touch area pattern.

Each sensor is scanned separately to see if a finger is present. While it is scanned all the other sensors serve as ground. With this method it is possible to get coordinates of the fingers location. In this way the horizontal and vertical groups of pads represent x and y coordinates, respectively. (Grivna and Berry[16])

9.2.5 Diplexing – an I/O pin saving method

Because the number of input and output (I/O) pins on the microprocessor is limited it could be advantageous to use a pin saving method. Diplexing is such a method. It is only possible to implement when using sliders, though. With diplexing it is possible to connect two sensors to only one pin. The sensors must be arranged in a certain order, for instance in the way shown in the figure below (See figure 39). With that certain pattern for the diplexed sensors any confusion is avoided where a finger is located even though more sensors, than them actually having a finger present, are activated. (Lee 2008a, p. 5-6)

[16]Grivna, E & Berry, S, Sr. Architect MTS & Sr. Product Marketing Manager, Cypress Semiconductor Corporation, lecture slides

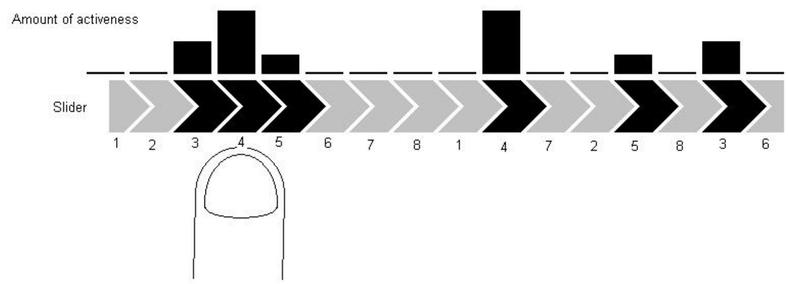


Figure 39 - Diplexing example.

9.2.6 Parasitic capacitance

Parasitic capacitance is also known as stray capacitance. It commonly exists on a printed circuit boards. The parasitic capacitance occurs between parallel traces or between traces or planes on opposite sides of the PCB. The effect of parasitic capacitance can lead to serious performance problems; examples include greater noise, reduced frequency response and instability. (Guinta 1997)

9.3 Tuning of a Cypress *CapSense* CSD Design

The following sections explain how to tune a *CapSense* application using CSD. At first some useful theory about the measurement technique is described which is important for the later described tuning procedure. A laboratory experiment will show how the tuning of a touch sensor can be done in practice.

9.3.1 *CapSense* measurement technique

Cypress Semiconductors uses a method with a continuously updated baseline to monitor capacitance on a sensor. The principle is that the baseline is the reference for *CapSense* measurements and each sensor has its own baseline. In figure 40 the basic parameters are shown and are described shortly below. (TrueTouch Gesture Data Sheet 2008, p. 12).

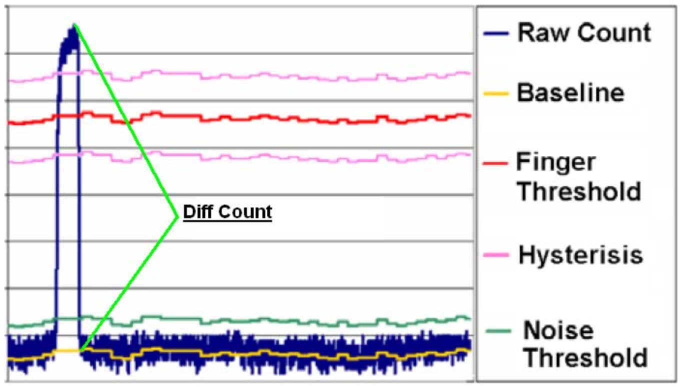


Figure 40 - Output from a *CapSense* sensor (modified by Karl Löfgren). (Lee 2007a)

Raw Count:
Raw Count is the output value of the signal level of a sensor. The *PSoC* devices have different available filters, *User Module*[17] parameters, which can be used to filter the raw count for e.g. improving the SNR. (TrueTouch Gesture Data Sheet 2008, s.12)

Difference Count:
As seen in figure 40 the *Difference Count* is the difference between the *Baseline* and *Raw count*. It is used to determine if a finger is present, as well as calculating the precise location of the finger. (TrueTouch Gesture Data Sheet 2008, s.13)

Baseline:
The baseline is a trend line for a capacitive sensor data that is computed by the baseline function of the *CapSense User Module*. The *Baseline* is supposed to remove the effect of slow movement in the *raw count,* e.g. temperature or supply voltage changes. (TrueTouch Gesture Data Sheet 2008, s.12)

Finger Threshold:
This is the signal threshold for when a sensor will be considered to be pressed. *Finger threshold* is compared to the *Difference counts* of the sensor. The finger position will not be calculated until the finger threshold is exceeded. (TrueTouch Gesture Data Sheet 2008, s.13)

[17]A *User Module* is a block of digital or analog components in the *PSoC* that can be programmed to different functionalities. (PSoC Designer 5.0 2008)

Hysteresis:
The hysteresis can be described as a parameter that affects the valid value of *Finger Threshold* to get a more stable operation. When using hysteresis the *Count value* has to be greater than the *Finger Threshold+Hysteresis* to change the sensor state from off to on. The *Count value* has to be lower than *Finger Threshold–Hysteresis* to change from on to off. (Tsui 2007, s.5)

Noise Threshold:
The noise threshold can be described as a threshold which will decide whether the baseline is updated or not. The *Baseline* will only be updated by raw counts below the noise threshold and above the *Baseline*. The noise threshold should be set slightly higher than the peak-to-peak value of the noise. (Tsui, T. 2007, s.5)

The parameters described above are only the basic parameters. When designing projects in the software *PSoC Designer 5.0* also other parameters need to be set. Figure 40 shows some parameters which could be set and downloaded to the *PSoC* device while tuning through software. The parameters that are not described earlier are presented in the following sections.

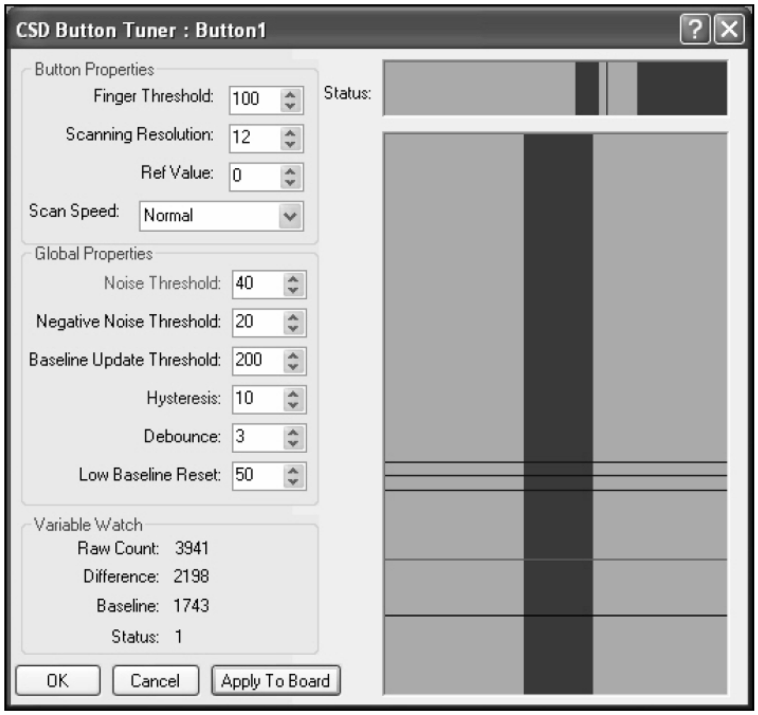


Figure 41 - The button tuner in *PSoC Designer 5.0* with its changeable parameters.

Scanning Resolution:
This parameter determines the output resolution of the sigma-delta converter. Increasing the resolution improves the sensitivity and SNR of touch detection. The resolution is directly proportional to the conversion time. For example a 9-bit conversion will take half the time of a 10-bit conversion. (*CapSense* Sigma-Delta Data Sheet 2008, p. 38)

Ref Value:
This parameter sets the comparator reference voltage, which is derived from V_{DD}. For example if the parameter is set to 0, then $V_{ref} = 1/4V_{DD}$. Lower value of parameter V_{ref} gives more sensitive CSD sensors. This is based on the theory of the CSD algoritm. The voltage on C_{mod} must reach V_{ref} before the comparator trigs, thus the value of V_{ref} will affect the amount of time it takes for C_{mod} to charge to V_{ref}. A good starting point for the *RefValue* is 4. This allows more flexibility in values later in the design process. (Tsui, T. 2007, s.7)

Scan Speed:
The scanning speed controls how fast the CSD *User Module* performs a scan. Slower scanning speeds results in less influence of power fluctuations and higher SNR. The scanning speed is directly proportional to the A/D conversion time. (*CapSense* Sigma-Delta Data Sheet 2008, p. 38)

Negative Noise Threshold:
It is similar to *NoiseThreshold,* i.e. a limit which will decide whether the *Baseline* is updated or not. The difference is that the negative noise threshold is below the *Baseline*. (Tsui 2007, p. 5)

Baseline UpdateThreshold:
The BaselineUpdateThreshold can be described as a parameter that sets how frequent the baseline is updated. Lower values give more frequent updates. (*CapSense* Sigma-Delta Data Sheet 2008, p. 36)

Debounce:
When using debounce on a sensor you introduce a time frame when the sensor must have a specific signal level before being considered as active. (Tsui 2007, p. 6)

Low Baseline Reset:
If the count value is less than *Baseline-NegativeNoiseTreshold* for the number of samples set by *Low Baseline Reset*, the baseline is set to a new *Raw Count* value. *Low Baseline Reset* is generally used to correct for a start up condition when a finger is placed on a sensor. (Tsui 2007, p. 5)

9.3.2 *CapSense* tuning procedure

Before tuning a new *CapSense* design there are some things which should be thought of. The following factors and variables affect the tuning settings:

- Overlay thickness and dielectric constant
- Geometric dimensions of the sensors
- Sensor connection resistance to the *PSoC* device
- Conditions such as:
    - Presence of a power supply
    - Temperature
    - Humidity
    - Presence of moisture
    - ESD, EMC or EMI requirements
    - Air gaps between the PCB and overlay

The tuning procedure is done by changing parameters in the *CapSense User Module*s and changing external components. The *User Module* parameters are changed in the *Cypress* software *PSoC Designer 5.0* and are loaded to the *PSoC* device. The external feedback resistor R_B is a component that requires tuning for optimal performance of sensors. That is because the resistor R_B determines the range of capacitance that is measured with CSD. *Raw Counts* are proportional to the parasitic capacitance C_p and because this capacitance is not known for a new design the resistor R_B must be adjusted to accommodate higher or lower values of $C_{p.}$ The goal with tuning a CSD project is to set the *Raw Count* level near 50% of the maximum count level 2^N where N is the *Resolution* parameter. The reason for this is that the system is more tolerant to bad sensor design if a greater variance of raw counts is allowed. All *Raw Counts* have to be between 25-85% of 2^N and the *Raw Counts* are allowed to have the greatest variance if the average *Raw Counts* are tuned to 50%. (*CapSense* Sigma-Delta Data Sheet 2008, p. 59), (Lee 2008a, p. 4)

A tuning procedure which could be used for a touchpad is described briefly below in five steps. The procedure is inspired by a flowchart for tuning CSD recommended by Cypress Semiconductors. (Lee 2008a, p. 3)

1. Choose appropriate initial values for User Module parameters and R_B

Before measuring raw counts some initial parameters have to be set. R_B should be set to a low value to allow measurements of a large range of capacitances. Cypress semiconductors recommends a value of R_B = 2kΩ as initial value. Three *User Module* parameters (*N*, *Ref Value* and *SysClk*) need to be set in the software. Below three example values are presented.

N = 16 bit
Ref Value = 4
SysClk = 24 MHz

These parameters are set in the *CSD Properties* and *Global Resources* when programming the microprocessor function in *PSoC Designer 5.0* (See figure 41). (Lee 2008a, p. 4)

2. Measure Raw Counts

After setting the initial values some measurements have to be done of the *Raw Counts* of the design. During measurements a real-time monitor tool is needed. There are several ways of connecting the tuning object to a computer. It is possible to send or debug signals on a computer via I2C communication by using Cypress' *I2C Communication Bridge,* a device that adapts the signals from I2C to USB. The future HID prototype would be equipped with a USBUART for the connection to a PC (described in chapter 9.4.1). It is easier to view the *Raw Count* when the data is presented in a spreadsheet.

Using cypress software makes it quite easy to read the data and view the *Raw Count* as a spreadsheet. In *PSoC Designer 5.0* you can choose monitor mode. When using this mode the test object is powered by the computer and the function can be tested in real time. Then choose *Variables Chart* and you get a spreadsheet which among other things plots the *Raw Count* and *Baseline* as a function of samples.

For tuning the *CapSense* sensors you have to find the sensor with the highest value of parasitic capacitance (C_p) which is equivalent to highest *Raw Count*. Each sensor has a slightly different value of C_p due to routing constraints. The external component R_b should be tuned to the sensor with highest value of C_p as told in the introduction of this chapter. (Lee 2008a, sp 3)

3. Calculations and tuning of external components

After the first measurement of *Raw Counts* the new value of the external feedback resistor R_b can be calculated. At first the highest measured value of *Raw Count* is placed as *Counts* in equation 1. Solving equ. 1 result in a value of C_p and this value is used to calculate a new value of R_b in equ. 2. The new value of R_b result in the measured *Raw Count* a baseline value of 50% of 2^N. One example from Cypress' home page is shown below.

$$C_P = \frac{Counts}{2^N \times R_b \times \left[\frac{SysClkl}{4}\right] \times \left[\frac{1}{\left(\frac{1}{4}+\frac{REF}{16}\right)} - 1\right]} \qquad \text{(equ. 1)}$$

$$newR_b = \frac{50\%}{C_P \times \left[\frac{SysClk}{4}\right] \times \left[\frac{1}{\left(\frac{1}{4}+\frac{REF}{16}\right)} - 1\right]} \qquad \text{(equ. 2)}$$

<u>Example 1:</u>

N=16bits *f*=6MHz *Counts*= 9830

REF(*ref value*)=4 R_b=2kΩ

f = The system clock frequency for *CapSense* input (*SysClk* = *PSoC* system clock)

Equ 1, where $f = \frac{SysClk}{4}$ => C_p= 12.5pF.

Equ 2, where C_p= 12.5pF => newR_b = 6.6kΩ (Lee,M. 2008a, s.3-4)

4. Tuning in software
When the external resistor is tuned to an acceptable value some software changes should be made to improve the functionality to the *CapSense* sensors.

Changing in the software means setting the recently described parameters (described in 9.3.1). This is done using the earlier described monitor mode where the parameters can be changed and the result can be viewed (See figure 41). The threshold values must be tuned in every new design to get a proper functionality.

Cypress recommends the following threshold values:

- Noise threshold = 40%*S (S = signal)
- OFF threshold =60%*S (Off threshold = [FingerThreshold+Hysteresis])
- ON threshold = 90%*S (On threshold= [FingerThreshold-Hysteresis])

(Lee,M. 2007b, p. 2-3)

With these recommendations *Finger Threshold* and *Hysteresis* can be determined:

- *Hysteresis* = $\frac{ONThreshold - OFFThreshold}{2}$
- *Finger Threshold* = $\frac{ONThreshold + OFFThreshold}{2}$

Note that one example on how to calculate S and the thresholds from spreadsheets with *Raw Counts* are presented in example 1 below. These recommended threshold values can only be used when SNR is at least 5:1.

There are other parameters than the thresholds that can be set. It is not possible to give these parameters settings that fit every *CapSense* design but some examples of how they can be used in general are presented below.

<u>The sensitivity is too low:</u>
The *Ref Value* can be used to adjust the sensitivity of a sensor (described in 9.3.1). (*CapSense* Sigma-Delta Data Sheet 2008, p 65)

<u>The SNR is too low:</u>
If the SNR is too low this could be solved by increasing the scanning resolution. One thing you should think about when increasing the scanning resolution is that the cost in scanning time is increasing (described in 9.3.1). It is possible that you have to make some design changes if the SNR is too low, this is further discussed in step 5. (*CapSense* Sigma-Delta Data Sheet 2008, p. 65)

Fluctuations in power supply:
If the power supply fluctuates the influence of these can be reduced by using a slower scanning speed. (*CapSense* Sigma-Delta Data Sheet 2008, p. 66)

Environmental changes:
For making the design safe from false button presses due to e.g. temperature a tuning of the *Baseline Update Threshold* parameter is important (described in 9.3.1).

5. Check Raw Count and SNR etc
The last step of the tuning procedure is to make the final measurements and tests. One good test is to expose the design for a worst case scenario. Use a finger simulator to be sure that the device works reliable in different conditions.

One example of a slight touch is to use a 10mm unconnected coil as a finger simulator. Move the coil across the button using a dielectric object. (*CapSense* Sigma-Delta Data Sheet 2008, p. 61)

As mentioned the raw count value of each sensor has to fall between 25% – 85% of 2^N before the tuning procedure can be finished.

It is very important to check the SNR for the design. The SNR should be measured in environments where the design would be used or in a worst-case noise conditions. It is the *Raw Counts* that are going to be observed when measuring the SNR. The SNR minimum requirement according to cypress is a ratio of 5:1 for a design. (Lee 2007b, p. 3)

If the SNR is below the minimum the easiest way of increasing it is to change a software parameter e.g. *Scanning Resolution*. It is not always that a change in the software is possible or solves the problem. A design change could be the solution to improve the SNR e.g. the overlay thickness could be decreased. After having checked the design for layout parameters that could increase the SNR, filtering could be used to minimize the noise. A simple IIR filter may be all that is required to get decent SNR. (Lee 2007b, p. 3)

Example 1
This example has the purpose to show how SNR and thresholds are calculated from *Raw Count* data taken from a spreadsheet.

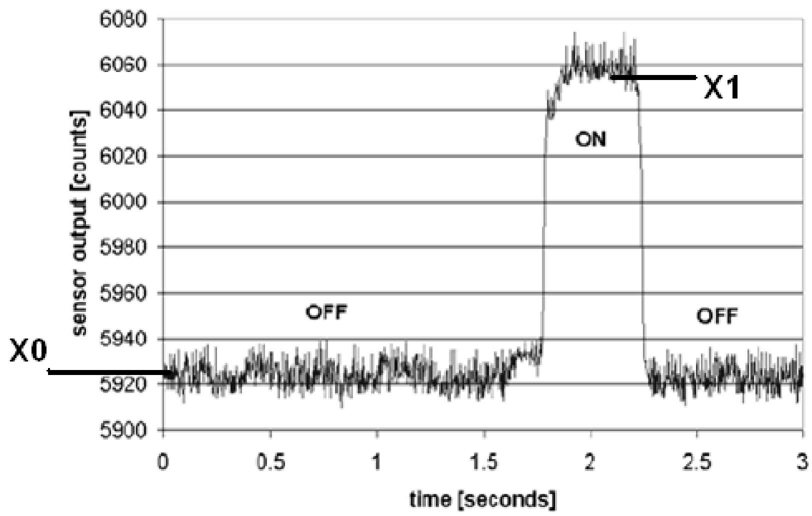


Figure 42 - Spreadsheet of the *Raw Count* and time. (Lee 2007b, p. 1)

X0 = 5925 counts
X1 = 6055 counts
S = X1-X0 = 130 counts
N = 5940 - 5925 = 15 counts
SNR = 130:15 = (8.6:1) > (5:1)
NoiseThreshold = 40%*130 = 52 counts
OFF Threshold = 60%*130 = 78 counts
ON Threshold = 90%*130 = 117 counts
Hysterisis = (117-78)/2 = 19 counts
Finger Threshold = (117+78)/2 = 97 counts

9.3.3 Experiment with tuning

Purpose

The purpose of the experiment was to see whether or not it was possible to tune a *CapSense* CSD touch button on an evaluation board CY312 (See figure 1 in *Appendix H*) to work with a 3 mm plastic or glass overlay, due to their difference in permittivity (described in chapter 9.1.3). The experiment is also meant to show how a tuning procedure is done in practice. The tuning procedure, described in the chapter 9.3, that was used is made up of five steps. The button is considered to be possible to tune when the signal to noise ratio (SNR) 5:1 is achievable. The SNR is the relation between the

PSoC:s output difference, when a button is on and off, and the difference between the highest and lowest noise output. (Lee 2006, p. 2)

Implementation
The evaluation board CY3121 does not support the CSD method for touch sensing that is recommended to be used in a possible HID solution in the future. Therefore it was modified to enable CSD (See marking 1 in figure 1 in *Appendix H*). A 2,2kΩ resistor in parallel with a trace was connected to two different pins on the *PSoC* of the board. After joint together the resistor and the trace were connected in series with a capacitance of 0,1nF and then to ground. The modification was done according to the schematics of more advanced evaluation boards supporting CSD and the component selection according to the recommendations from the Cypress support division[18]. (*PSoC* Express Evaluation Kit 2007, p. 3)

In the experiment a plastic and a glass 3 mm window were used as overlay. The windows were simply held over the button to simulate an overlay. It was done carefully because changes in the distance between the overlay and the button could have caused quite big disturbances on the output. However, the reliability of the experiment is doubtable because of the air gap between the button and the overlay could have weakened the output significantly according to the factors to consider in chapter 9.3.2.

<u>1. Choose appropriate initial values for *User Module* parameters and R_b:</u>
The top left quadrant of the board (See marking 2 in figure 1 in *Appendix H*) was programmed with *PSoC Designer 5.0* to make use of one touch button and one LED that should be lit up while the button was activated. How the *PSoC* should be programmed was inspired by a project from another evaluation board's kit guide. At first a CSD button *User Module* and a driver *User Module* was created with the parameters *Resolution* set to *12* and *Ref Value* set to *4* in the *CSD properties* (See figure 43). The parameter *Power Setting* in *Global resources* was set to *5.0V/24MHz* (See figure 43). The *Resolution,* the *Ref Value* and the *Power Setting* are the initial values for the *User Module* parameters and were taken from the description of step 1 in the chapter 9.3.2. An I2C *User Module* was created to handle the communication of the *PSoC*. After that the pins of the *PSoC* were assigned, according to figure 44 below, the project was built and the *PSoC* was programmed. (CY3209-ExpressEVK Kit Guide 2007, p. 35)

[18]Prashanth, Sai, Support Consultant, Cypress Semiconductors Corporation, e-mail correspondence 17/12 2008

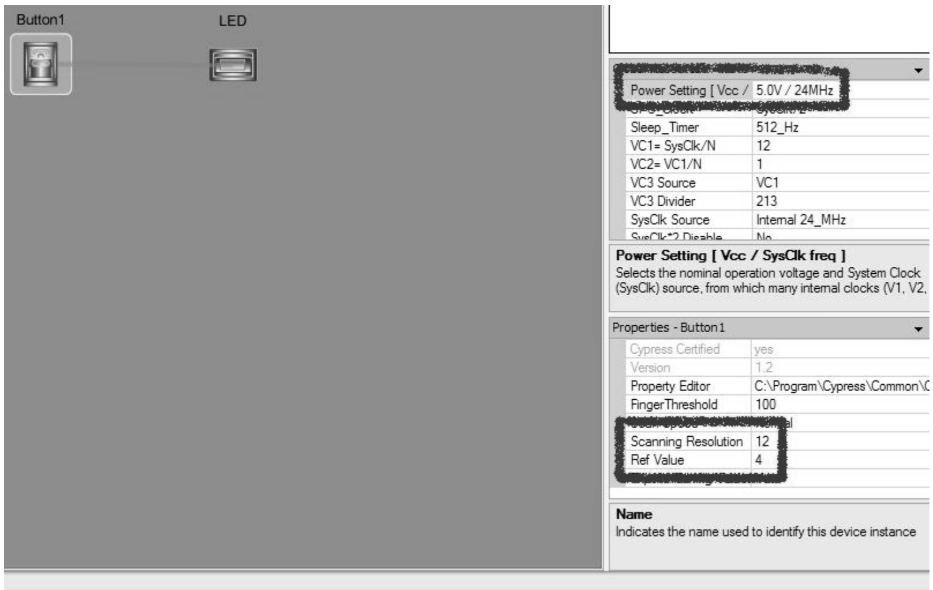


Figure 43 - Parameters to set in *PSoC Designer 5.0*. (PSoC Designer(TM) 5.0 – Software and Drivers 2008)

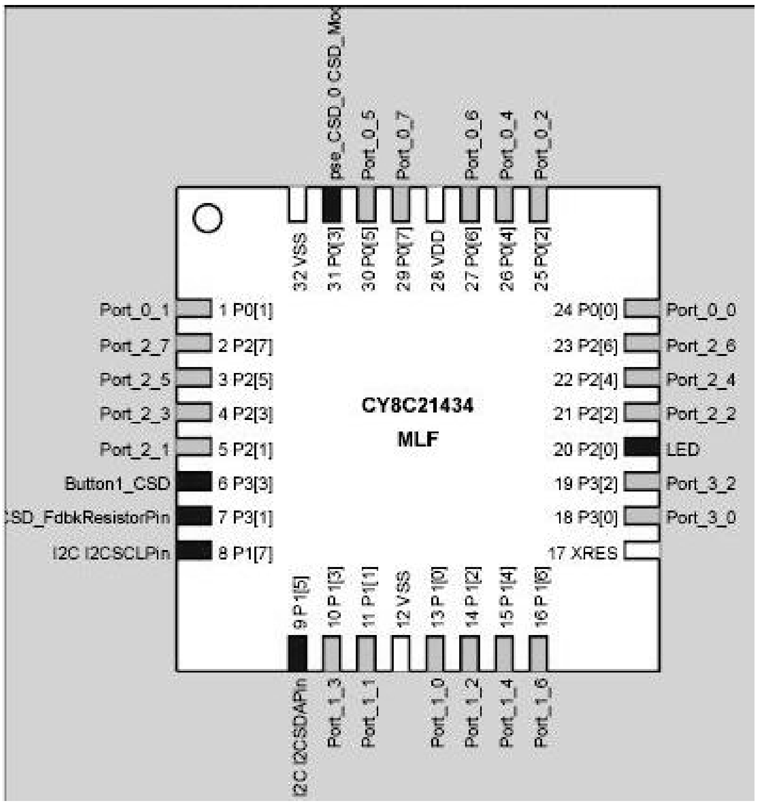


Figure 44 - Pin assignments in *PSoC Designer 5.0*. (PSoC Designer(TM) 5.0 – Software and Drivers 2008)

<u>2. Measure *Raw Counts*:</u>
To be able to measure the raw counts of the *PSoC* a communication with a computer was established. The top right quadrant (See marking 3 in figure 1 in *Appendix H*) of the evaluation board was programmed to work as an I2C to USB bridge to run the communication. How the *PSoC* should be programmed was inspired by a project from another evaluation board's kit guide. The project was built and the bridge programmed. Now the board was ready to be connected with the computer. (CY3209-ExpressEVK Kit Guide 2007, p. 35)

The raw counts (explained in chapter 9.3.1) were plotted into a graph in the program *I2C-USB program*[19] supplied by Cypress. A more extensive account of the conception raw count is done in chapter 9.3.1.

The graph from the *I2C-USB program* (See figure 45) showed that the difference in the output when a finger pressed the button was around 30 raw counts (See figure 45). A 2.2k**Ω** resistor, a 0.1nF capacitor and a plastic overlay was used. The biggest value measured which was to be used in the calculations of step 3 was 509 raw counts.

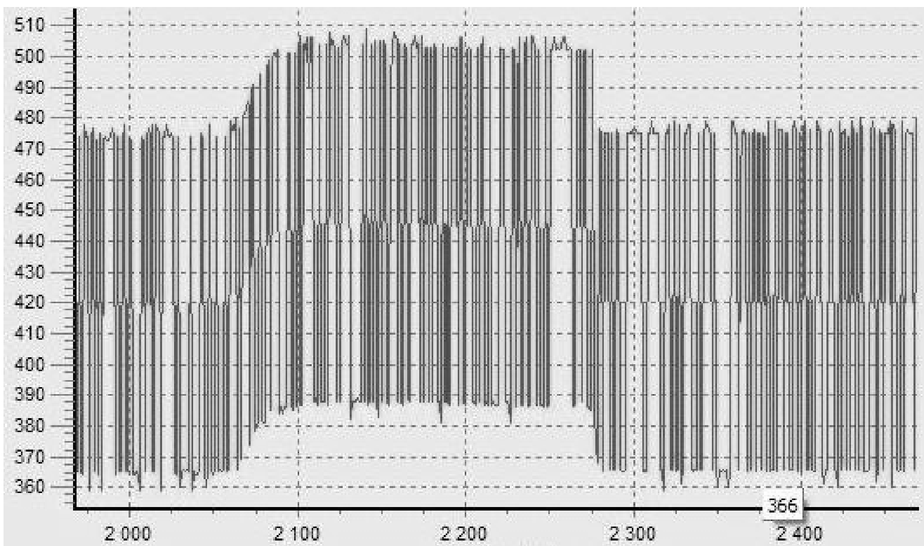


Figure 45 - Output in *I2C-USB program* when the button is pressed with a plastic overlay and a resistor of 2,2k**Ω**. The unit of the x axis is raw counts and samples count of the y axis. (CY3240-I2USB – Developers Kits 2008)

Then the same procedure was done with the glass overlay, the 2,2k**Ω** resistor and the 0,1nF capacitor. The difference in the output when the button was pressed was 50 raw counts (See figure 46). The biggest raw count value measured was 564 (See Figure 46).

[19] The I2C-USB program is a software program that plots the output of a PSoC device in a spreadsheet. (CY3240-I2USB – Developers Kits 2008)

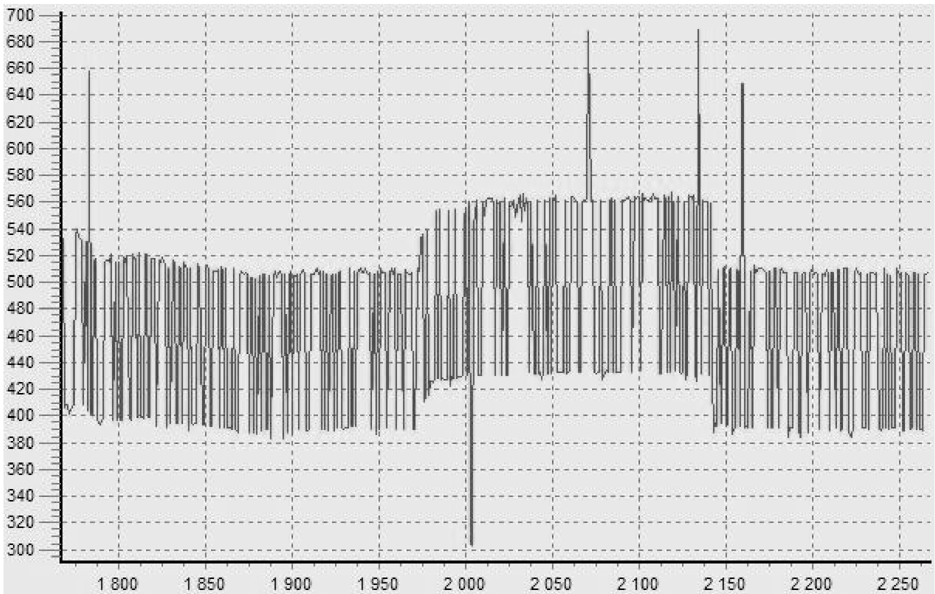


Figure 46 - Output in *I2C-USB program* when the button is pressed with a glass overlay and a resistor of 2,2kΩ. The unit of the x axis is raw counts and samples count of the y axis. (CY3240-I2USB – Developers Kits 2008)

3. Calculations and tuning of external components:

The equations used to calculate the value of the new R_b were the ones displayed in step 3 in the chapter (9.3). At first the R_b for the solution with the plastic overlay was calculated. The raw count 509 from the previous step and *SysClk = 24 MHz* and *Ref = 4* from step 1 were used in the equations.

$$C_P = \frac{Counts}{2^N \times R_b \times \left[\frac{SysClkl}{4}\right] \times \left[\frac{1}{\left(\frac{1}{4}+\frac{REF}{16}\right)} - 1\right]} = 9{,}41\,pF$$

which lead to

$$newR_b = \frac{50\%}{C_P \times \left[\frac{SysClk}{4}\right] \times \left[\frac{1}{\left(\frac{1}{4} + \frac{REF}{16}\right)} - 1\right]} = 8,86k\Omega$$

Then a new R_b for the solution with the glass overlay was calculated with the same equations. For this solution the raw count 564 from the previous step was used.

$$C_P = 10,4\,pF$$

which lead to

$$newR_b = 8,01k\Omega$$

When doing the experiment the only available source of components was the workshop at the department of *Industrial Electrical Engineering and Automation*. The resistor with the most accurate resistance to both of the calculated new R_bs was 8,2k**Ω**. Then the new resistor was mounted on the evaluation board.

4. Tuning in software:
Tuning in software meant that the parameters, described in the chapter 9.3*,* were to be set in the monitor mode of the program *PSoC Designer 5.0*. To calculate the parameters *Noise threshold*, *ON threshold* and *OFF threshold*, the signal (S) had to be measured. In step 3 the signal, i.e. the difference in output between the on and off state, was measured. But now the resistance of R_b was changed. Therefore the measurements of step 2 had to be done all over again with the new R_b of 8,2k**Ω**. This resulted in the new greatest raw count measurements of 1955 with the plastic overlay (See figure 47) and 2185 with the glass overlay (See figure 48). The signal with the plastic overlay was 50 (See figure 47) and with the glass overlay 90 (See figure 48). However, a notation in the chapter 9.3.1 claimed that the equations to calculate the thresholds only were applicable if the SNR was 5:1. To review this, the noise was measured in figure 47 and 48. The noise in the case with plastic overlay was 140 raw counts which resulted in a SNR of 50:140 which is equivalent to 0,357:1. This meant that the ratio was not at all close to the minimum recommendation. Therefore, in this case, the equations for the thresholds were not valid. The noise in the case with the glass overlay was 100. This resulted in a SNR of 90:100 which is equivalent to 0.9:1 and also meant that the equations were not valid. An attempt to set the thresholds manually was done but in both cases the settings lead to an

unstable button. False button presses occurred frequently. No other parameter was changed. The one that should have been changed, in case of a low SNR, was the *Scanning Resolution* but that was impossible because it was already at its highest level.

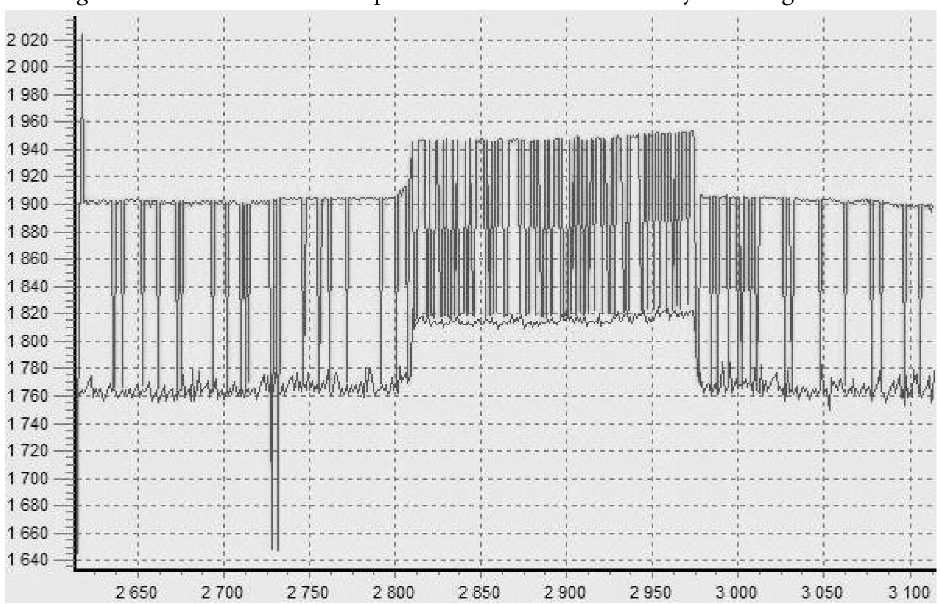


Figure 47 - Output in *I2C-USB program* when the button is pressed with a plastic overlay and a resistor of 8,2k**Ω**. The unit of the x axis is raw counts and samples count of the y axis. (CY3240-I2USB – Developers Kits 2008)

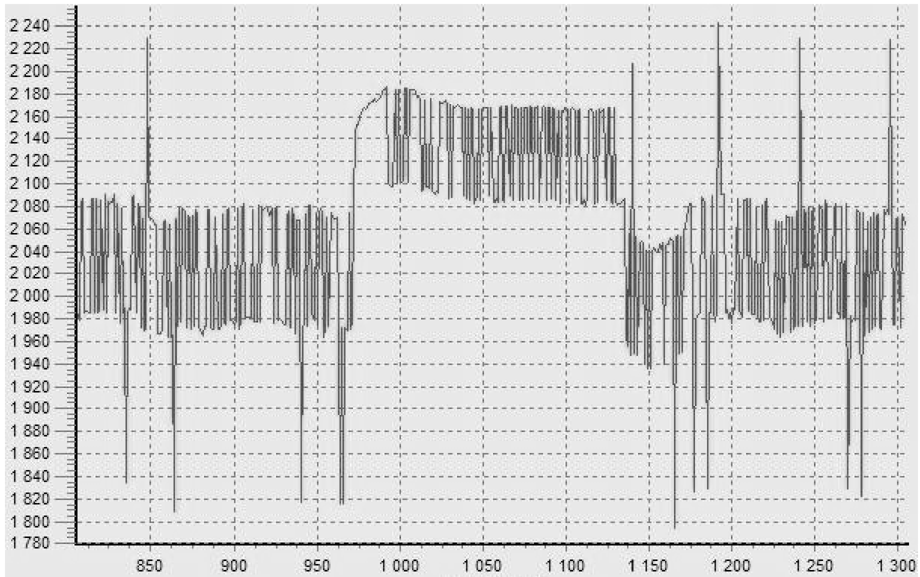


Figure 48 - Output in *I2C-USB program* when the button is pressed with a glass overlay and a resistor of 8,2k**Ω**. The unit of the x axis is raw counts and samples count of the y axis. (CY3240-I2USB – Developers Kits 2008)

<u>5. Check raw counts and SNR etc:</u>
Nothing practical was done in this step because the SNR did not exceed the minimum requirement of 5:1.

There were some PCB layout changes recommended in step 5 like decreasing overlay thickness or using an IIR filter. Decreasing overlay thickness was not done because the test was supposed to be done with a 3 mm overlay according to the purpose of the experiment. Adding an IIR filter to the design was not done because it was considered to be too demanding by the project group to alter the evaluation board even more.

Conclusions
The button was not considered to be tuneable neither with plastic nor glass overlay because the SNR did not exceed the minimum limit of 5:1. However, it could be plausible to make a better PCB design with a corresponding button and overlay tuneable, if the layout guidelines to achieve better SNR were followed more strictly. For example the air gap between the button and the overlay could have caused the low SNR in the experiment. The gap could have been avoided with adhesive film put in between.

9.4 Programming

9.4.1 Programming the touch area of a HID

The software, *PSoC Designer 5.0* , provided by the microprocessor manufacturer makes it quite easy to program the function of the HID. To be able to program the touch area of the HID a touchscreen *User Module* must be created in the software. The *User Module* makes it possible to program the HID through an API supplied by Cypress.

When the touchscreen *User Module* is created, the sensors has to be assigned to the right pins. This is done in the *User Module* wizard. Thereafter it is possible to do the programming through the API. Using the code from the API the sensors should be scanned and the result evaluated and stored in specific registers. The stored values should then be sent via USB, according to the supervisor, to the CPU of the operator panel. How communication via USB works is described in the next section. However, the microprocessor CY8CTMA120 has, unlike the CY8C21 434 of the evaluation board, two pins with direct USB functionality. The evaluation board's *PSoC* has to communicate via I2C with an I2C-to-USB bridge to connect to a computer. (TrueTouch™ Gesture Data Sheet)

9.4.2 Programming the communication between the HID and the CPU unit

The easiest way, according to the supervisor, for the HID to communicate with CPU unit is to connect it via USB. The microprocessor of the HID should be programmed to behave in accordance with the protocol of the standard of a *USB HID class*[20]. Then the CPU unit considers it to be the same sort of device as a mouse or a touchpad etc. (USBFS Device Data Sheet Controller 2008, p. 2)

To make the CPU unit understand the HID some descriptors must be programmed. A descriptor is a package of information about the device gathered in a certain amount of bytes. These packages are requested from the USB host, in this case a computer (but the CPU unit in the case with the concept proposals), when it notices a connected USB unit. The class descriptor is the descriptor indicating it is a USB HID. (Designing a Low-Cost USB Mouse with the Cypress Semiconductor CY7C63000 USB Controller 1997, p. 8)

[20] A USB HID Class is a USB device class that describes human interface devices such as keyboards and mice. (Designing a Low-Cost USB Mouse with the Cypress Semiconductor CY7C63000 USB Controller 1997, p. 5)

The descriptors are programmed in the software *PSoC Designer 5.0* that is used to program the *PSoC*. To be able to program the descriptors a USBFS *User Module* must be created in the software. A USBFS *User Module* is a low level driver that handles requests from the USB host. The USBFS *User Module* enables a setup wizard for the descriptors in the software where it is easy to fill in the characteristic values of the HID. Then to be able to use the HID, code must be written in the software using the API of the USBFS *User Module*. (USBFS Device Data Sheet Controller 2008, p. 2-3)

9.4.3 Experiment with a HID communicating as a mouse

The document *USBFS Device Data Sheet* from Cypress' home page provided some sample code for the *PSoC* Designer program to make a *PSoC* with a USB connection on an evaluation board CY3121 (See figure 1 in *Appendix H*) work as a mouse. In the experiment the steps of the *USBFS Setup Corresponding to the Example Code* chapter in the document were followed in the implementation. (USBFS Device Data Sheet 2008, p. 12-13, 14-16)

Purpose
This experiment was done to get an idea of how a HID could communicate with a CPU unit (in this case a computer) in a future operator panel concept.

Implementation
At first a USBFS *User Module* was created in *PSoC* Designer. When that was done the USB setup wizard was enabled. In the wizard a human interface device was chosen. Then the template of a 3 button mouse was imported. Then it was up to the programmer to choose which different descriptor attributes to fill in. The 3 Button Mouse was chosen in the HID Report field of the HID Class Descriptor. Now, when the descriptors were configured the application was generated.

Finally the sample code, from the *USBFS Device Data Sheet* document, was pasted into the "main.c" file of the *PSoC* designer project and the project loaded to the top right quadrant of the evaluation board (See marking 3 in figure 1 in *Appendix H*). When the USB cable was properly connected between the PCB and the computer the PCB was installed as a USB device.

Now, on the display of the computer it was possible to see the mouse courser move from left to right and right to left over and over again as it was instructed by the sample code in "*main.c*".

Conclusions

In the same way as in this experiment the HID of a future operator panel concept could be programmed to function as a USB mouse or another form of USB HID. The data that should be sent to the computer by the USB *User Module* could be gathered from a Touchscreen *User Module* on the *PSoC* that would handle the HID's .

10 Conclusions and Recommendations

Several new technologically innovative concepts were generated but many of them were soon rejected, in the chapter *Selecting Product Concepts,* because of their use of new unreliable technology. Instead concepts with innovative mechanical design with the new input unit called HID seemed to be the most suitable for the future.

Below the advantages, disadvantages and conclusions of the final three concepts are presented. All of them fulfil the requirement with the so called “building block” principle.

Concept 14 - The HID and display unit is in concept 14 hidden behind a glass window which makes the components very isolated from the surrounding environment. The glass window leaves a nice and plane area without joints for the user’s input. The concept is easy to mount. The only disadvantages with the presented 3D design are the dimensions and weight but this could easily be optimized.

Concept 13 - It is difficult to find a mechanical solution for docking a HID onto a base unit regarding isolation from the surrounding environment. However, the presented proposal had a rather good solution to the isolation problem. The main drawbacks were the large amount of joints and the difficulties in mounting.

Concept 27 - The later developed concept 27 is a better alternative than the other concepts considering size and weight. This concept is dependent on that the HIDs could be made relatively thin because they are mounted outside the wall. Robert Nordström actually made a statement that the HID units must be integrated with the display unit. However, the project team think it is wise to reconsider this concept with separate HIDs because it is rather difficult to achieve integrated HIDs.

After evaluating the presented 3D models the project group consider concept 14 and 27 as the best for a possible future generation of operator panels. Concept 13 could be used if a better docking principle would be developed. The earlier rejected proposal 18 (See chapter 6.3.1) was based on the principle to only use a big touchscreen. If a touchscreen as big as the front of concept 14 was used, input areas corresponding to 14’s HIDs could be implemented in software. Then the same functionality and appearance could be achieved with only one big touchscreen. Therefore the project group recommends Beijer Electronics to reconsider concept 18 because it would probably be cheaper to develop and manufacture than concept 14.

The materials and manufacturing methods presented are not surprising in any way. The recommended material for the frames in the final concepts is die-casted aluminium like in the *EXTER* series.

The recommended material for operator panel windows is glass. Smaller details like the HID fixture and the component fixture are recommended to be moulded in plastic material.

With the theory, PCB layout guidelines and practical experiments presented in this Master Thesis it should be possible to get a working prototype of a touchpad using capacitive touch technology.

There are not so many others factors to consider when designing the touchpad PCB compared to regular touch buttons or sliders. There is one important thing to remember that is hard to imagine when making tests on regular touch buttons, though. That is when designing a touchpad the overlay material has to be thinner compared to when designing buttons or sliders.

The source of the capacitive touch method and theory presented is Cypress Semiconductor Corporation. The project team can recommend Cypress Semiconductor Corporation as a supplier of usable capacitive touch technology for a future HID prototype.

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Appendix A – Rejected Proposals

Rejected Proposals from the First Brainstorm

Proposal 2 – Display unit with separate HID unit and an electronics box

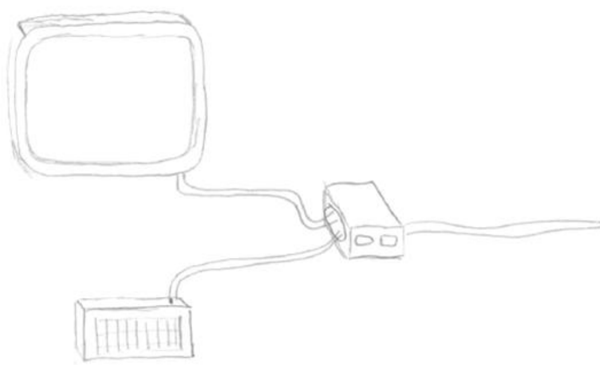

Figure 1 – Sketch of proposal 2

Description:
This proposal resembles the concept of a desktop computer. The operator panel consists of a display unit and a HID unit that is connected to a separate box, which contains the electronics. This concept gives the customer a bit more flexibility in the placement of the components. For example the electronics box can be mounted in a cupboard or simply be places in a desk drawer.

Advantages:
- The display unit can be made thinner when the electronics do not have to be placed behind the display
- More flexible placement of the concept components
- Possibility to choose the amount of HID units

Disadvantages:
- This concept increases the number of connections, hence more wires
- Not possible to mount as one unit

Comments:
According to Robert Nordström this idea already has been discussed at Beijer Electronics but the conclusion is that this concept generates technical problems. It is the communication between the display and the electronics box that causes the problems. The result of these problems is a flickering display. It is possible to correct this problem but then you will end up with a much higher cost that is not reasonable.

Because the technical problems this proposal is to be rejected.

Proposal 3 – Expansion box

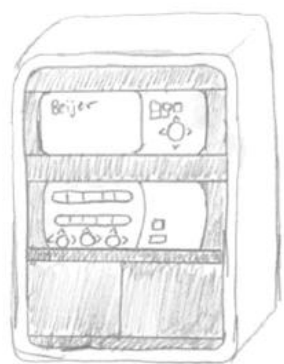

Figure 2 – Sketch of proposal 3

Description:
The idea is to have a box or a locker where the customer can place optional units. The spaces, which are not occupied by the building blocks, will be covered with dummy material to isolate the panel and get an esthetical design. The box or frame could be mounted into the wall or be a detached unit.

Advantages:

- The electric components are isolated from the environment
- Possibility to choose the amount of HID-units
- Mounted as one unit

Disadvantages:

- Because of standardised sizes of the frame it could lead to unused space
- Hard to clean because of joints
- If the frame or box is not mounted into the wall it will require a lot of space

- The maximum amount of HID units is limited
- Not flexible because all building blocks have to be within the frame

Comments:
A possible scenario is that the customers want to change the size of the frame or box. This problem can be solved by manufacturing the frame in different sizes. Another problem with this proposal is the joints between the building blocks and the dummy material, which will attract dirt and bacteria.

The proposal is to be rejected.

Proposal 5 – Extremely thin display without touch-technology and separate HID unit and electronic box.

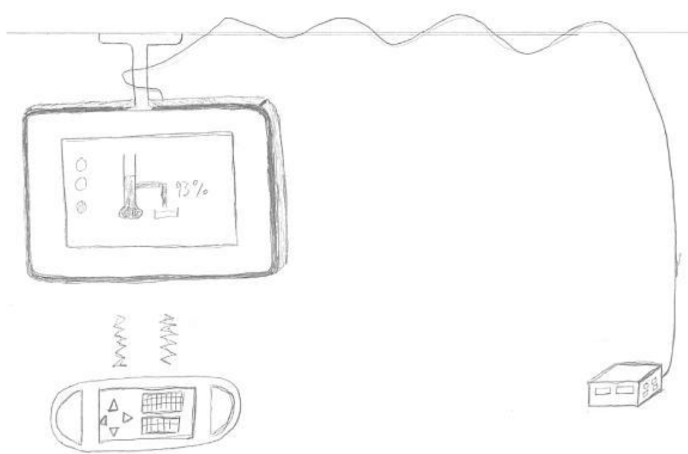

Figure 3 – Sketch of proposal 5

Description:
The idea is to use an extremely thin display and to mount it on a wall hold. The display will only visualise what happens in the application without any input opportunities. The new technology with displays on paper materials is in special interest for this proposal. The idea with a separate electronic box is not new for this proposal and has been described earlier. The input is handled by a wireless HID unit similar to a remote control.

Advantages:
- Light and thin display unit

Disadvantages:

- Unsafe with a remote(could be misplaced or cause unwanted inputs)
- Not a possibility to choose the amount of HID units (i.e. the "building block" principle is not applied)
- The remote control does not cover the need for buttons
- Not possible to mount as one unit
- Hard to clean

Comments:
The separate electronic box generate technical problems earlier described (proposal 2). The security is jeopardised with a remote control. If the remote does not have a certain placement when not used it is easily lost or damaged. The possibility to press buttons by mistake is obvious. Using new technology with displays made of paper material could result in an appealing design but it would be far too expensive.

This proposal is to be rejected based on the comments above.

Proposal 6 - Rails

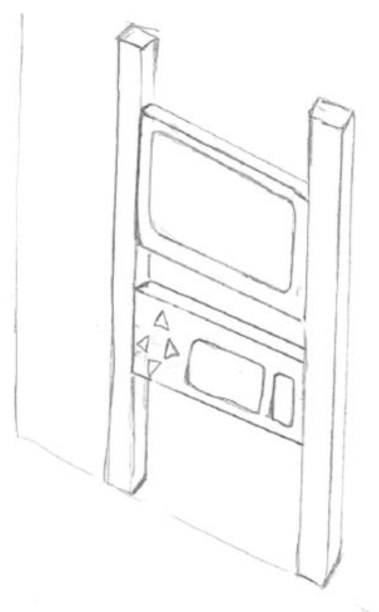

Figure 4 – Sketch of proposal 6

Description:
This proposal is founded on the principle to have a separate display and HID unit. The idea is that these units will be mounted on the wall on two rails. The electronics are placed behind the two components. Rails can make the mounting easy and the position for display and HID unit can be changed vertically.

Advantages:
- The components can be adjusted vertically
- Possibility to choose the amount of HID units
- No need for a big mounting hole in the wall

Disadvantages:
- Hard to clean
- Require a lot of free space for the rails
- Not flexible because all building blocks have to be mounted within the rails

Comments:
The fact that this proposal is difficult to clean is a big problem. If the display and HID unit have a cover, which will protect them from the environment, one part of the problem is solved. But using two rails mounted on the wall makes it very hard to satisfy the hygiene demands.

This proposal is to be rejected based on the comments above.

Rejected Proposals from the Second Brainstorm

Proposal 16 – Extractable input unit

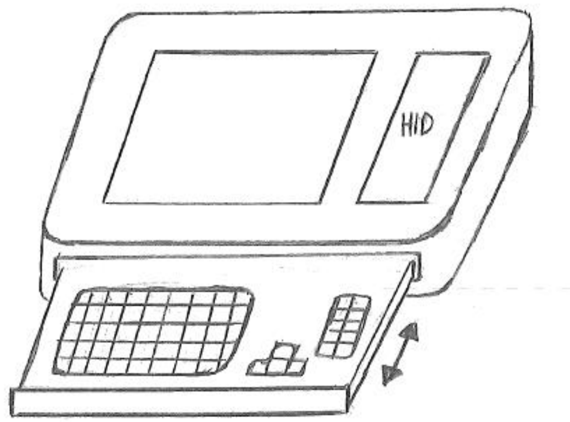

Figure 5 – Sketch of proposal 16

Description:
The display is mounted into the wall but is sticking out that much that there's room for a keyboard behind the display. The keyboard is extracted when it is needed.

The keyboard consists of a programmable HID. The space where the keyboard is located is completely isolated from the rest of the electronics.

Advantages:
- Does not use much space when it is not used
- Mounted as one unit

Disadvantages:
- Protruding a lot outside the wall
- Uses a lot of space when it is used
- Hard to clean
- Maximum of HID units is limited
- Not a possibility to choose the amount of HID units (i.e. the "building block" principle is not applied)

Comments:
The proposal is to be rejected.

Proposal 17 – All units in one frame without window

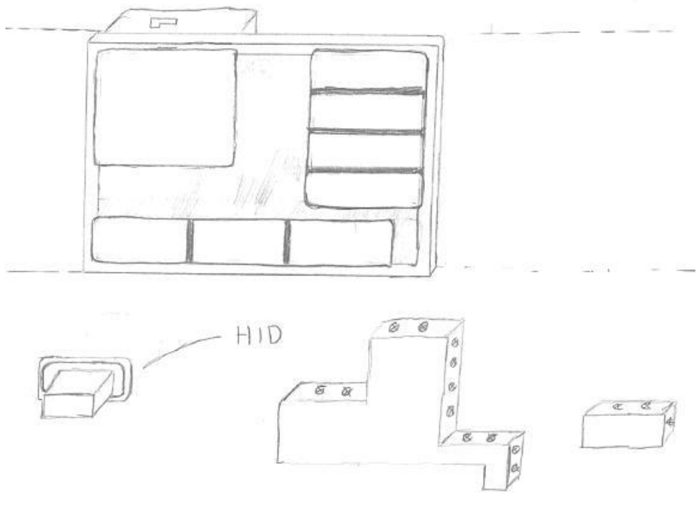

Figure 6 – Sketch of proposal 17

Description:
The proposal consists of a thin frame where the display and HID units will be mounted. The idea is that the customer himself should be able to configure the amount and placement of the HID units and the size of the display. The units will be fixed with a fixture unit that also serves the purpose to fill empty space. The electronics are enclosed on the backside of the frame. It is the enclosing itself that is mounted into the wall and should keep the panel in place. Note that the back part does not cover the entire frame. A part of the frame hangs freely on the wall. It is possible that the part of the frame that hangs freely need an extra attachment. All the HID units are of the same size. Not only the frame has to be made in different sizes to fit the customers need, also the fixture unit has to be in different sizes.

Advantages:
- Possibility to choose the amount of HID units
- Mounted as one unit
- With this type of back part there's no need for a big mounting hole

Disadvantages:
- Hard to clean because of joints
- A risk that the frame becomes thicker which will result in that a bigger part of the panel is protruding

- The maximum of HID units is limited
- Not flexible because all building blocks have to be within the frame

Comments:
The proposal will lead to too many joints. To mount only a section of the back part into the wall should be investigated further. The proposal is similar to proposal 3 that is rejected.

The proposal is to be rejected

.

Appendix B – Calculations on the Panel Window

In concept 14 the front of the panel is a solid pane of glass. If it is designed like that, the window has to be glued onto the frame. The panel is fastened onto the wall with screws that are fastened against the wall from the back (See figure 3 in *Appendix I*). Because of this type of fastening there is a force acting on the window that pushes it outwards from the glued joint. Whether or not it is reasonable that it is going to hold is investigated with following calculation.

For the relation between the axis force in a screw, F_S, and the torsion of the thread, M_G, the following formula is applied:

$M_G = F_S(0{,}16P + 0{,}58d_2\mu_G)$ (Burman 1996)

M_G = 1 Nm (E1012 - Installation Manual 2007, p. 8)

P = Thread gradient = 0,8 mm (Skruvförband 1996, s. 6)

d_2 = Thread mean diameter = 4,480 mm (Skruvförband 1996, s. 6)

μ_G = Thread friction coefficient = 0,16 (Montering, åtdragningsmoment och krafter)

Through the formula F_S = 1839 N was calculated. Because the total amount of screws that fixes the frame are 4 then $F_{tot} = 4F_S$ = 7356 N. The limit of stretching strain, σ, for a common industrial adhesive for glass and metal is 26 MPa. (UV härdade glaslimmer 2008)

To calculate the area that is needed to keep the frame and glass together the relation between stress and force is:

$$\sigma = \frac{F}{A} \Rightarrow$$

$$A = \frac{7356}{26 \times 10^6} = 0{,}0002829 = 2{,}829cm^2$$

Only an area of 2,829 cm^2 between the glass and the frame need to be jointed by adhesive to resist the force on the window in the assembly. Because the locating face between the glass and the frame easily could be made larger than 2,829 cm^2 it is assumed that an adhesive joint will hold.

Appendix C – Needs

Table 1- Needs from interviews with customers.

From Customer Interviews	Conclusion of the project group
Less metal frame around the display. Reduce the build-in-depth.	-
IP-classified cover with VESA hold	If the customers want a VESA hold then they probably want the opportunity to fasten the operator panel on a free hold. Then you have to consider a water and dust proof cover. Cables etc should also be easy to fasten with for example clips.
Wireless portable input-device	-
The input device should both have ordinary buttons and touch buttons.	-
Smooth surfaces, no edges on the front where micro organisms can grow. (for food and pharmaceutical industry)	-
USB and card readers should be accessible from the front. Should be IP44-classified.	It is preferable if USB and other outputs and inputs are easy to access. It is very important that the operator panels are safe from unauthorized persons and that sabotage is avoided. These two needs counteract each other.
Tempered glass for public applications.	Stronger glass in applications where vandalism occur
Sun readable operator panels for marine and outdoor applications.	-
Possibility to have two displays with only one CPU.	-

Table 2 - Needs from *Project Description*.

From the Project description	**Conclusion of the project group**
Mechanical (LEGO) Think LEGO, of course not on the same level, but the idea is that you would have different building blocks that you can mount together in a series of custom made products.	The customer will be able to build their own customized operator panel. Beijer Electronics will not produce special units for one individual customer. Instead the modification will be done by simply add the building blocks needed. One example: Beijer Electronics has before been forced to manufacture operator panels with an extra large keyboard. With the new concept they will be able to just add extra keyboard units(HID units) if they want more buttons. The new concept is supposed to contain both cheaper and more expensive operator panels.
Electronics- Keyboard decoding (Flexible layout) In extreme cases the customer should be able to make his own keyboard layout and print it from a regular printer. One other scenario is that the customer should be able to use a part of the display as a keyboard.	Beijer Electronics have the requirement that the new concept will allow the customer to modify the input unit after the application needs. The electronic for the input unit needs to be designed.
Design Design work would only be performed if the time allows it.	Beijer Electronics have won design awards for their products. They find it quite important that their new concept keep the design standard of the older versions.

Appendix D – Evaluation of the Proposals

Table 1 - Concept scoring table of concept proposals. The concepts are rated from 1 to 5 for every criterion according to the opinions of the project group. Rating 1 fulfil the criterion the least and rating 5 the most.

	Proposal	11		12		13		14	
Selection criteria	**Weight**	R	W.S	R	W.S	R	W.S	R	W.S
The customer should be able to assemble the operator panel himself according to his own needs	15	5	75	5	75	5	75	4	60
The operator panel should have as few joint as possible on the front	10	3	30	3	30	3	30	5	50
It should be possible to get an appealing design	2	3	6	3	6	3	6	5	10
The operator panel should be possible to mount into walls	10	5	50	2	20	5	50	5	50
There should be a possibility to choose the size of the buttons	4	5	20	5	20	5	20	4	16
The mounting should be flexible	2	3	6	2	4	1	2	1	2
The size of the operator panel should be optional	4	5	20	5	20	5	20	3	12
The operator panel should have the appearance of one unit	4	3	12	3	12	3	12	5	20
The operator panel should be well-protected against the surroundings	10	3	30	3	30	4	40	5	50
The operator panel should be safe against sabotage and accidents	8	3	24	3	24	5	40	5	40
The input should be simple	8	5	40	5	40	5	40	5	40
The operator panel should be cheap to produce	5	4	20	4	20	4	20	4	20
The technology should be reliable	10	4	40	4	40	4	40	4	40
The operator panel should be adapted to mobile input units	2	4	8	4	8	4	8	1	2
The user should be able to work in an ergonomic position	2	2	4	2	4	4	8	2	4
The operator panel should not be protruding the wall too much	4	3	12	2	8	4	16	5	20
Total score:	100		397		361		427		436

Evaluation of the proposals cont.

15		18		19		20		21		22		23		24		25		26	
R	W.S	R	W.S	R	W.S	R	W.S	R	W.S	R	W.S	R	W.S	R	W.S	R	W.S	R	W.S
4	60	2	30	2	30	2	30	2	30	2	30	2	30	2	30	2	30	2	30
5	50	5	50	3	30	4	40	2	20	5	50	5	50	4	40	5	50	5	50
5	10	5	10	3	6	4	8	4	8	5	10	5	10	5	10	5	10	5	10
5	50	5	50	5	50	5	50	5	50	5	50	4	40	2	20	5	50	4	40
4	16	3	12	3	12	3	12	3	12	3	12	3	12	1	4	3	12	1	4
1	2	2	4	2	4	2	4	2	4	2	4	1	2	3	6	2	4	5	10
3	12	3	12	3	12	3	12	3	12	3	12	3	12	2	8	3	12	3	12
5	20	5	20	5	20	1	4	5	20	5	20	5	20	5	20	5	20	5	20
5	50	5	50	5	50	3	30	2	20	5	50	5	50	3	30	5	50	2	20
5	40	5	40	5	40	3	24	2	16	3	24	5	40	3	24	5	40	3	24
5	40	3	24	3	24	2	16	3	24	3	24	4	32	2	16	4	32	2	16
4	20	5	25	5	25	2	10	3	15	3	15	1	5	1	5	1	5	1	5
4	40	5	50	5	50	5	50	5	50	5	50	1	10	4	40	1	10	1	10
1	2	1	2	1	2	5	10	1	2	3	6	1	2	5	10	2	4	5	10
2	4	2	4	2	4	4	8	4	8	2	4	2	4	4	8	3	6	4	8
3	12	5	20	5	20	5	20	3	12	5	20	5	20	1	4	5	20	4	16
	428		403		379		328		303		381		339		275		355		285

Proposal 11 – Separate display and HID unit
Proposal 12 – Display unit with docked HID units
Proposal 13 – Display unit with dockable HID units
Proposal 14 – All building blocks in the same cover behind a glass window
Proposal 15 – All building blocks in the same cover with removable front
Proposal 18 – iTerm
Proposals 19 – Touchscreen with a transparent keypad
Proposal 20 – Touchscreen with a pointer remote and a storage box
Proposal 21 – Extensible touch display
Proposal 22 – Touch screen with pointer stick
Proposal 23 – Projected keyboard
Proposal 24 – Projector with remote
Proposal 25 – The operator panel with eye-track and voice or button acknowledgement
Proposal 26 – Projector remote

R = Rating
W.S = Weighted Score

Explanation of criteria and grading and motives of weighting:

The customer should be able to assemble the operator panel after his own needs, 15

Explanation of criterion:
The operator panel should be composed by building blocks so that the amount of input units, how big the display size is and the number of outlets is optional.

Explanation of grading:
The grading was done considering how optional the number of physical building blocks were. The greater amount of physical building blocks the better grade was received. Why proposal 18-26 received such a bad grade was because they either had input units implemented in software or rather small input area.

Motive of weighting:
This criterion is the most important because this was the fundamental idea for the new generation of operator panels of Beijer Electronics.

The operator panel should have as few joints as possible in the front, 10

Explanation of criterion:
If the operator panel has got many sharp edges on the front it is harder to clean.

Explanation of grading:
The suggestions with just a glass front or just a window in a frame do not have few edges and therefore received higher grades when for instance proposal 21 with an extensible window easily gets dirty when the window is extended and therefore received a low grade.

Motive of weighting:
It is important to some customers while others do not need operator panels that are easy to clean. Therefore the weighting is not the highest.

It should be possible to get an appealing design, 2

Explanation of criterion:
The concept's shaping should not make an appealing design impossible to a potential product.

Explanation of grading:
The proposals consisting of a front as one unit was considered to be easiest to get an appealing design with and therefore received higher grades.

Motive of weighting:
Because the design is done by an external company anyway, the project group does not put much importance into this criterion.

The operator panel should be possible to mount into walls, 10

Explanation of criterion:
The customer today has the possibility to mount the operator panel into the wall and probably wants that possibility in the future as well.

Explanation of grading:
Proposals 12 and 24 that received the lowest grades were mounted mainly or totally outside the wall.

Motive of weighting:
The criterion is important because most of the customers demand that it must be fulfilled.

There should be a possibility to choose the size of the buttons, 4

Explanation of criterion:
For instance the remote has got a limited area where buttons could be configured and therefore could be hard to use.

Explanation of grading:
The proposals that received the lowest grades had very limited area on which the size of the buttons could be configured. Why the touchscreen proposals received relatively low grades was because they if a bigger button was to be configured it would have to invade on the display space. This is because the largest display size is 15” according to the supervisor.

Motive of weighting:
It is an advantage to be able to choose the size of the buttons but it is a new function and is therefore nothing the customers has demanded before.

The mounting should be flexible, 2

Explanation of criterion:
The operator panel should maybe be possible to mount into the wall, on an arm, in a casing and so on.

Explanation of grading:
Almost all the proposals were adapted to be mounted into the wall and therefore were not suited for other mountings such as on an arm.

Motive of weighting:
There are few customers that for example want to mount an operator panel on an arm. Most of them choose to mount it into a wall. The criterion is therefore weighed quite low.

The size of the operator panel should be optional, 4

Explanation of criterion:
The customers want to optimize the size of the operator panel. Sometimes there is not that much space to mount the operator panel and therefore a compact and small panel is requested. Some of the proposals use too much space.

Explanation of grading:
Why the touchscreen proposals and all the components behind a window received the lowest grades was because they were meant to be produced in few frame sizes and therefore option in size was limited to the amount of frame sizes.

The operator panel should have the appearance of one unit, 4

Explanation of criterion:
Even though the operator panel is composed by several building blocks it should be possible to mount as seemingly one unit.

Explanation of grading:
The proposals with all components behind a window and the touchscreen proposals received the highest grade because the they seem like made up of one unit. Proposal 20 received the lowest because it consists of two separate units.

Motive of weighting:
According to the supervisor of Beijer Electronics some customers want it to be possible to mount the operator panel as one unit. Therefore the criterion is relatively important.

The operator panel should be well-protected against the surroundings, 10
Explanation of criterion:
The operator panel should be isolated against fluids, dust and so on.

Explanation of grading:
The proposals with a glass front got the highest grades because the components are completely isolated behind the front. One of the proposals that got the worst grade is the one with a remote projector. This is because all the electronics is protected just by the casing.

Motive of weighting:
To make the operator panel work as flawlessly as possible it is always important for the electronics to be protected against the surroundings.

The operator panel should be safe against sabotage and accidents, 8

Explanation of criterion:
No one should be able to access the electronics to deliberately or unconsciously harm it.

Explanation of grading:
Most of the proposals are considered to be safely encapsulated but some were less encapsulated and therefore received the lowest grades.

Motive of weighting:
In industries there must be no risk that accidents or sabotages the operator panels because it could cause too severe consequences. Therefore the criterion is highly prioritized.

The input should be simple, 8

Explanation of criterion:
It should be easy for the user to use the input function and to manoeuvre in the program.

Explanation of grading:
Proposals with separate HID units (not remote controls) received the highest grades because they are considered to have a more distinct input. The proposals where the manoeuvring is done through a remote received the lowest grade because the remote is considered to add an extra difficulty to the manoeuvring.

Motive of weighting:
It is important for the user to be able to work effectively without being restrained by a difficult input.

The operator panel should be cheap to produce, 5

Explanation of criterion:
-

Explanation of grading:
The proposals with fewer components, therefore easier to produce, received the highest grades. The proposals with newer technologies and expensive details (such as the projector) received the lowest grades.

Motive of weighting:
It is hard to motivate big production costs.

The technology should be reliable, 10

Explanation of criterion:
New technology is not very well-tried and therefore not suited for industrial applications.

Explanation of grading:
The proposals including newer technologies received the lowest grades. For instance the projected keyboard has just recently arrived on the market and is not well-tried in any application.

Motive of weighting:
The foremost important aspect of technologies in industries is reliability. A stoppage of production could be very costly.

The operator panel should be adapted to mobile input units, 2

Explanation of criterion:
The operator panel could for example need a docking station to the remote.

Explanation of grading:
The proposals encapsulated in one unit received the lowest grade because they do not allow possibilities to dock remote controls.

Motive of weighting:
Mobile input units are not something that usually is included with operator panels.

The user should be able to work in an ergonomic position, 2

Explanation of criterion:
The display or the input unit could need to be angled so that the operator does not need to work in uncomfortable positions.

Explanation of grading:
The proposals with a remote control and the one with an adjustable display angle are considered to be more ergonomic because they allow the user to operate in whatever position wanted and therefore received the highest grades.

Motive of weighting:
The operator panels of today in general do not offer much choice in ergonomic positioning. Therefore the criterion is weighted quite low.

The operator panel should not be protruding from the wall too much, 4

Explanation of criterion:
-

Explanation of grading:
The proposals mounted mainly or completely outside the wall received the lowest grade.

Motive of weighting:
The operator panels of Beijer Electronics do not protrude the wall that much and therefore it is relatively important to let it remain in that way

Appendix E – Material Data

Table 1 – Material properties of possible material candidates for the panel window in concept BA

Material	Transparency	Permittivity(Dielectric constant)	Weight(kg)(Volume = $9,61*10^{-4}$ m^3)	Hardness(Vickers(HV))	Price of raw material (SEK)
Soda-lime glass	Optical quality	7-7,6	2,35-2,39	439-434	21-25,1
Acrylic, PMMA	Optical quality	3,2-3,4	1,11-1,17	16,1-21,9	17,2-20
Cellulose polymers	Optical quality	3-5	0,942-1,25	10-15	23,5-34,1
Polystyrene	Optical quality	3-3,2	1,00-1,01	8,6-16,9	11,5-12,7

Table 2 – Material properties of possible material candidates for the fixture in concept BA

Material	E-modulus(GPA)	Density(kg/m^3)	Price(SEK/kg)	Castability	Moldability
Cast Aluminum Alloys	72-89	2.5-2.9e^3	16.4-18.1	4-5	-
Cast magnesium alloys	42-47	1.75-1.87e^3	28.9-31.8	4-5	-
Cast zinc alloys	68-100	4.95-7e^3	19.6-21.6	5	-
Polyoxymethylene (Acetal, POM)	2.5-5	1.39-1.43e^3	14.4-15.8	1-2	4-5

(Granta, CES EduPack 2008)

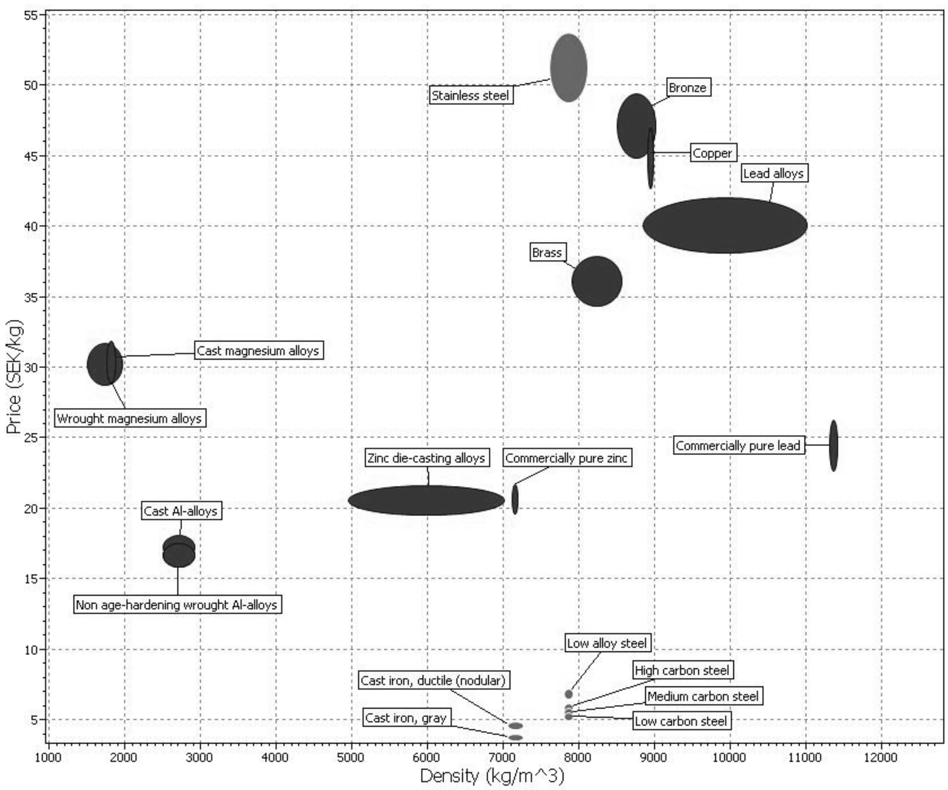

Figure 1 – Price in relation to the density of a number of metals.

(Granta, CES EduPack 2008)

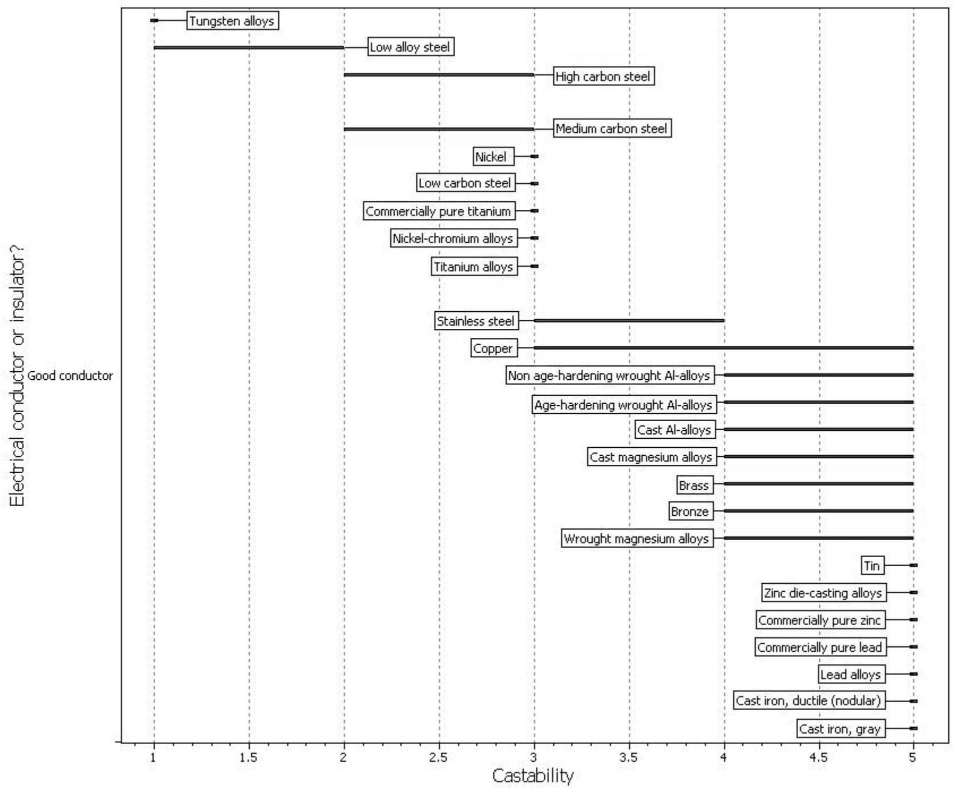

Figure 2 – Electric conductivity in relation to the castability for a number of metals.

(Granta, CES EduPack 2008)

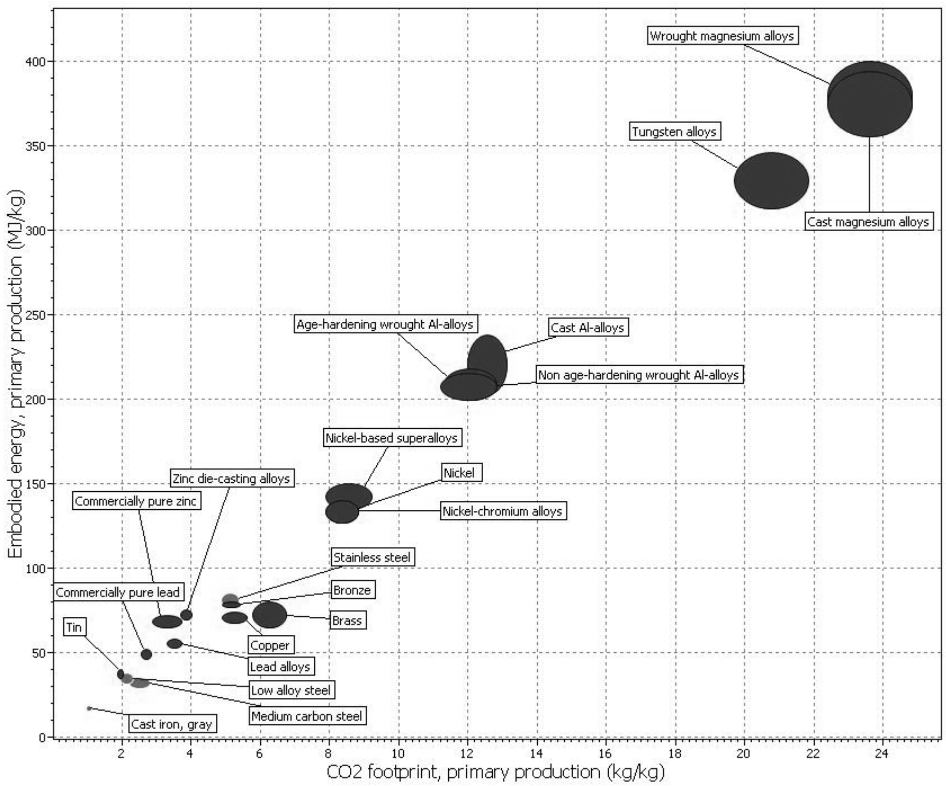

Figure 3 – Embodied energy in relation to CO_2 footprint (primary production) for a number of metals.

(Granta, CES EduPack 2008)

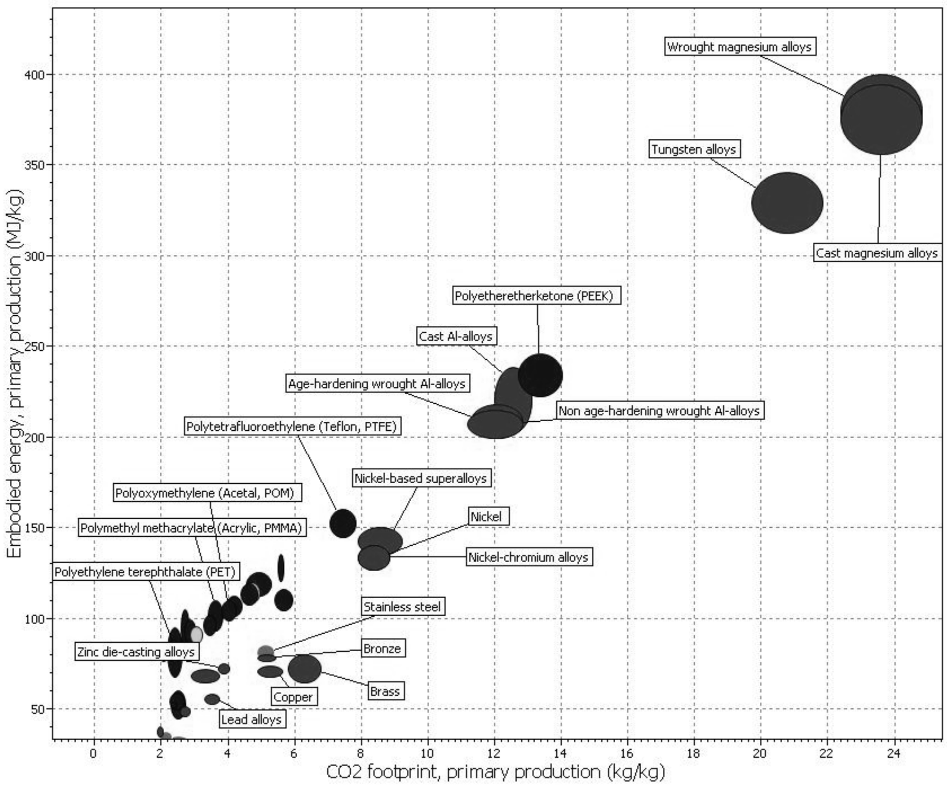

Figure 4 – Embodied energy in relation to of CO_2 footprint (primary production)

(Granta, CES EduPack 2008)

Appendix F – Weight of Concept Models

Part	Weight(kg)	Material	Amount
Concept BA			
Frame	0.95	**Aluminum**	1
Panel Window	2.48	**Soda-lime glass**	1
Fixture	0.16	**Polyoxymethylene(Acetal, POM)**	1
Back plate	1.65	**Aluminum**	1
Electronics casing	0.83	**Aluminum**	1
HID Fixture	0.03	**Polyoxymethylene(Acetal, POM)***	4
Widescreen 15"	0.57	**-**	1
HID	0.30	**Assumed value**	4
Total, (Total with 4HID:s)	7.96(7.96)		
Concept AC			
Frame	1.28	**Aluminum**	1
Panel window	0.40	**Soda-lime glass**	1
dummy	0.14	**Aluminum**	2,(0)
Back plate	0.41	**Aluminum**	1
Electronics casing	0.83	**Aluminum**	1
HID Frame	0.37	**Aluminum**	1,(4)
HID Fixture	0.03	**Polyoxymethylene(Acetal, POM)***	1,(4)
HID glass	0.06	**Soda-lime glass**	1,(4)
HID back plate	0.09	**Aluminum**	1,(4)
Frame remote control	0.45	**Aluminum**	1,(0)
Fixture remote control	0.07	**Polyoxymethylene(Acetal, POM)***	1,(0)
Widescreen 15"	0.57[1]	**-**	1
HID	0.30	**Assumed value**	1,(4)
Total:	5.14 (6.89)		
Concept AD			
Frame	0.92	**Aluminum**	1
Panel Window	0.40	**Soda-lime glass**	1
Back plate	0.41	**Aluminum**	1
Electronics casing	0.83	**Aluminum**	1
HID Frame	0.30	**Aluminum**	2,(4)
HID glass	0.07	**Soda-lime glass**	2,(4)
HID Fixture	0.03	**Polyoxymethylene(Acetal, POM)***	2,(4)
Widescreen 15"	0.57[1]	**-**	
HID	0.30	**Assumed value**	2,(4)
Total:	4.53 (5.93)		

*This is not the selected material but it gives a good value of the density

Appendix G – PCB Design and Schematic

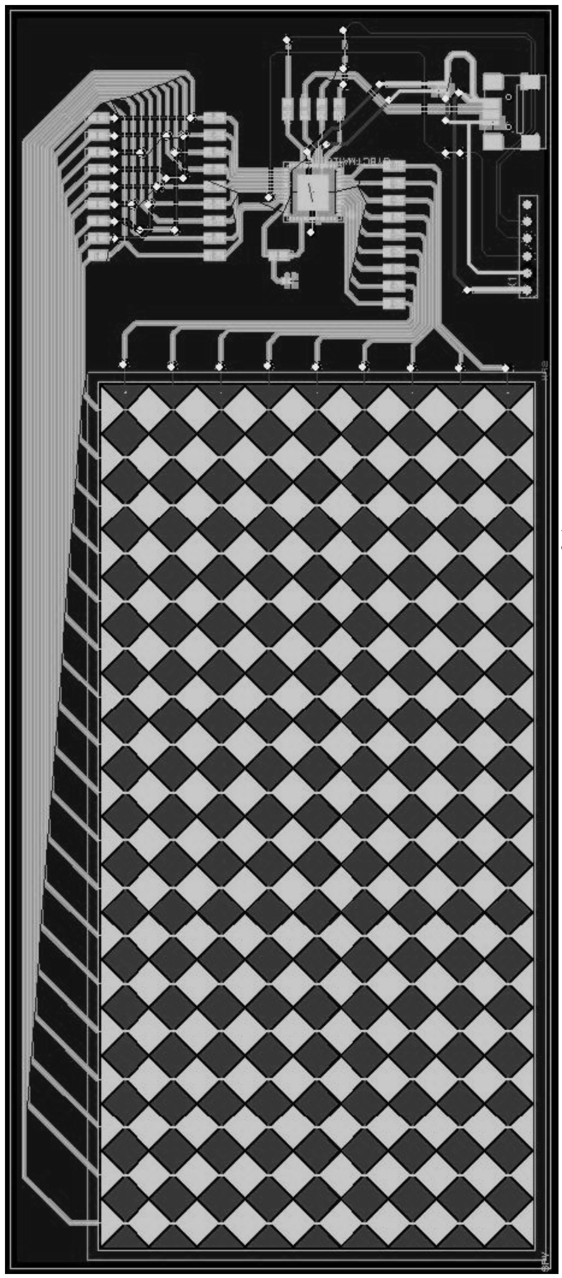

Figure 1 – CAD Design of the PCB

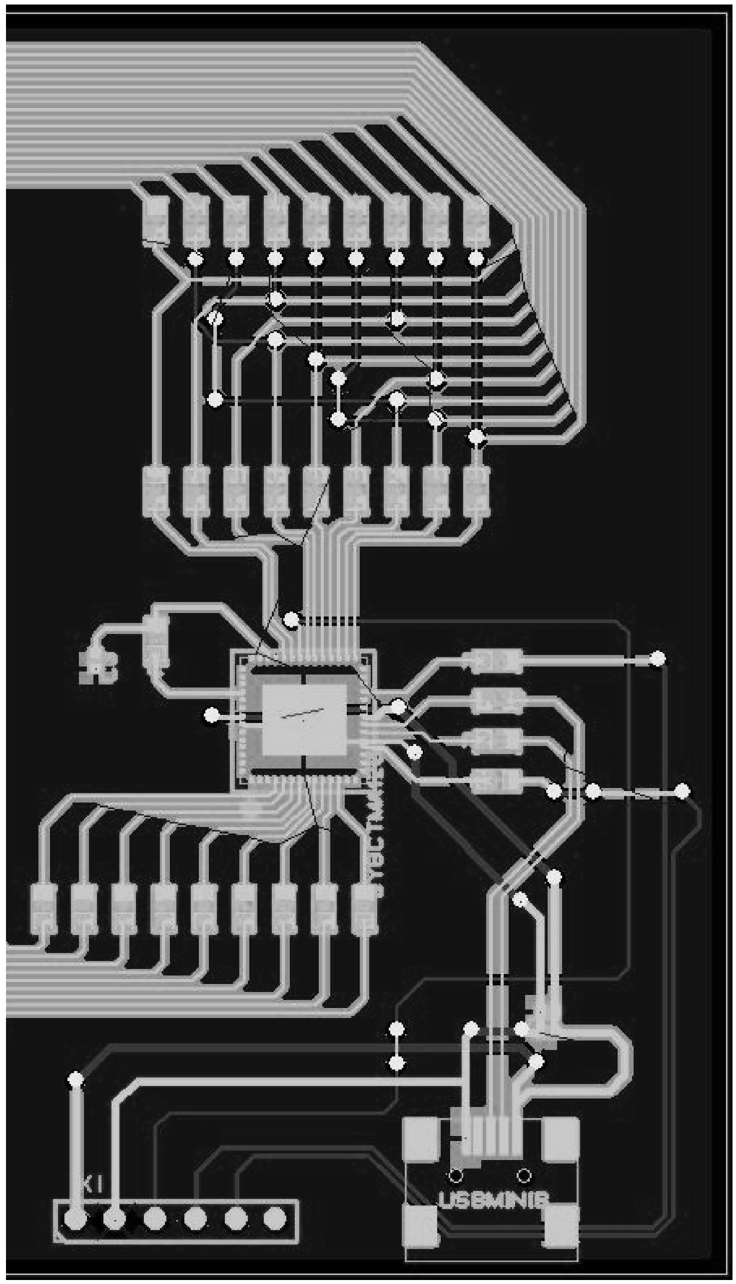

Figure 2 – CAD design of the PCB

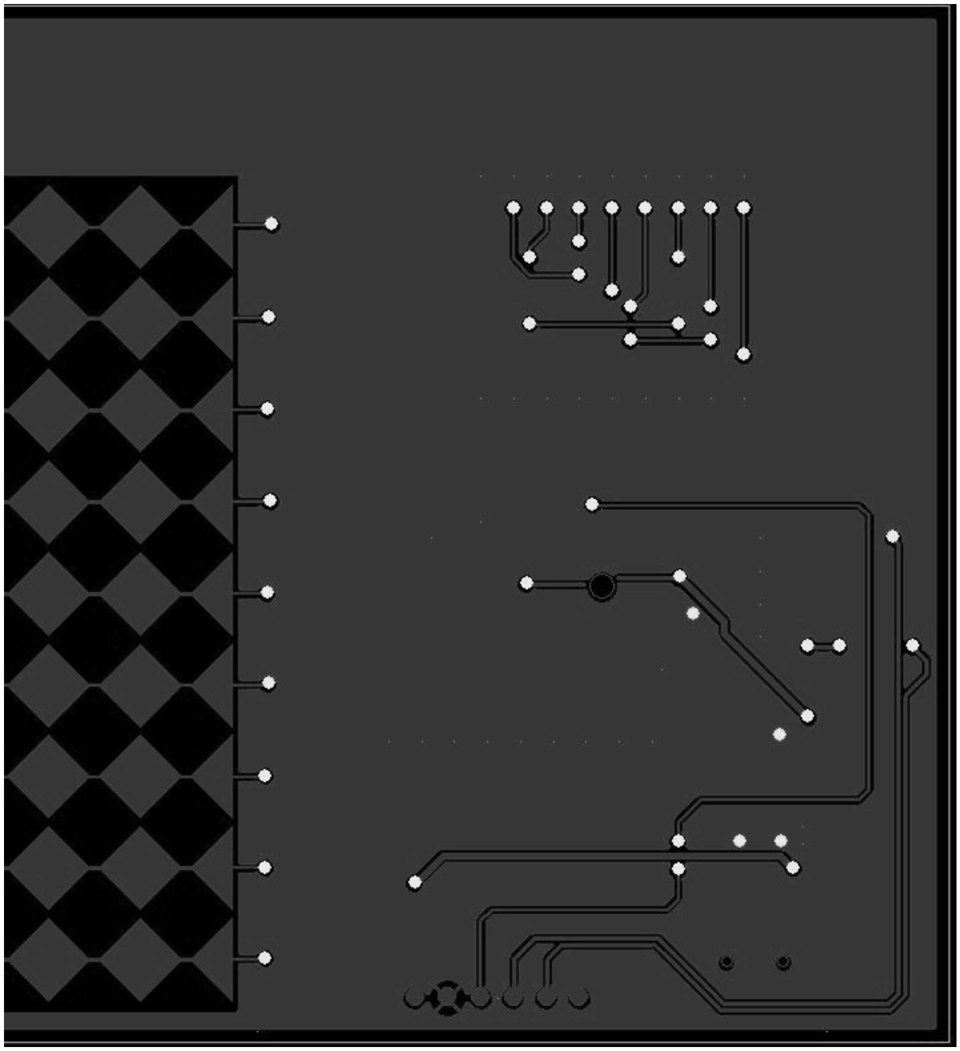

Figure 3 – CAD design of the PCB (bottom layer)

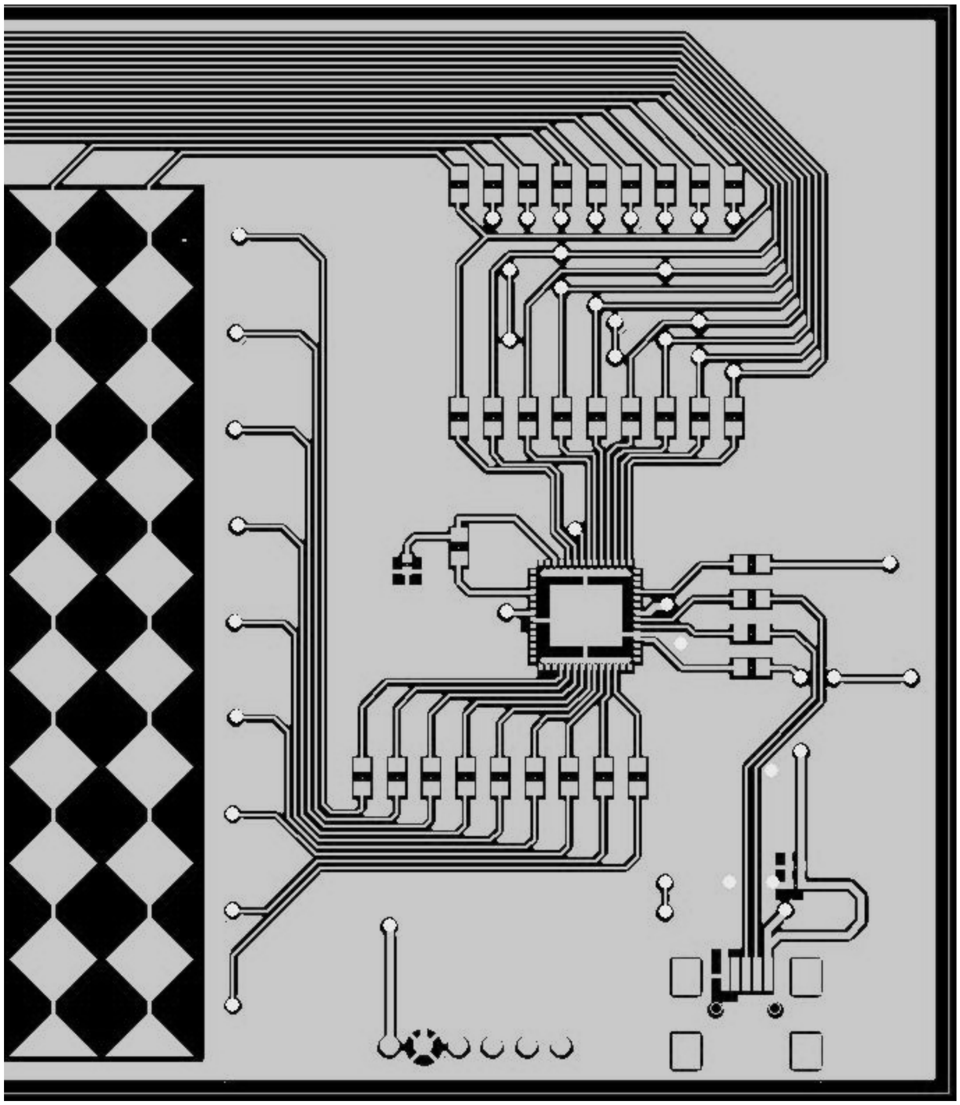

Figure 4 – CAD design of the PCB (top layer)

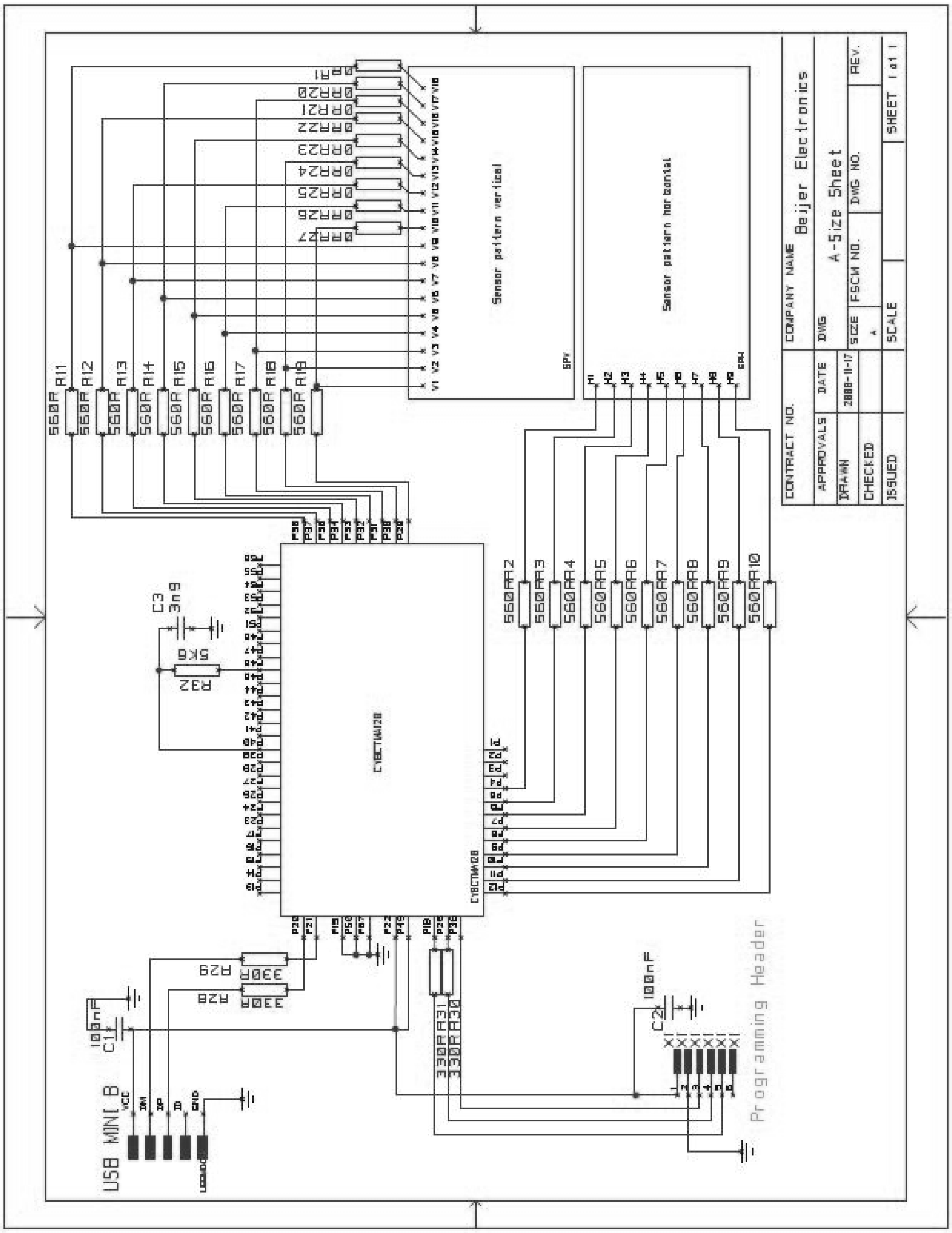

Figure 5 – Schematics of the prototype

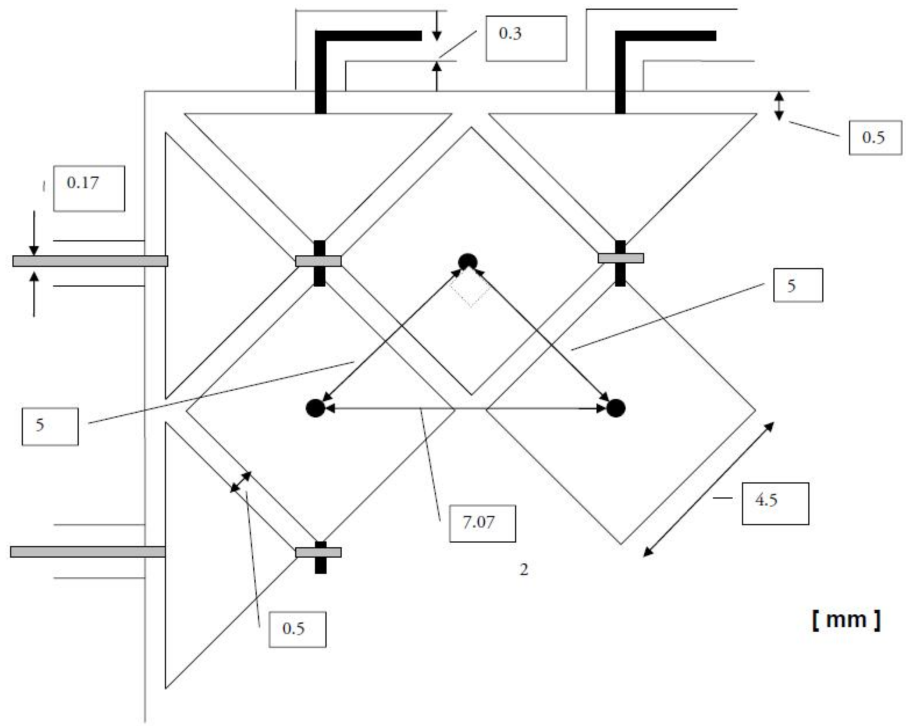

Figure 6 – Sensor pattern. Note that this pattern does not completely follow the recommendations from Cypress due to reasons described in chapter.

Appendix H – Evaluation Board

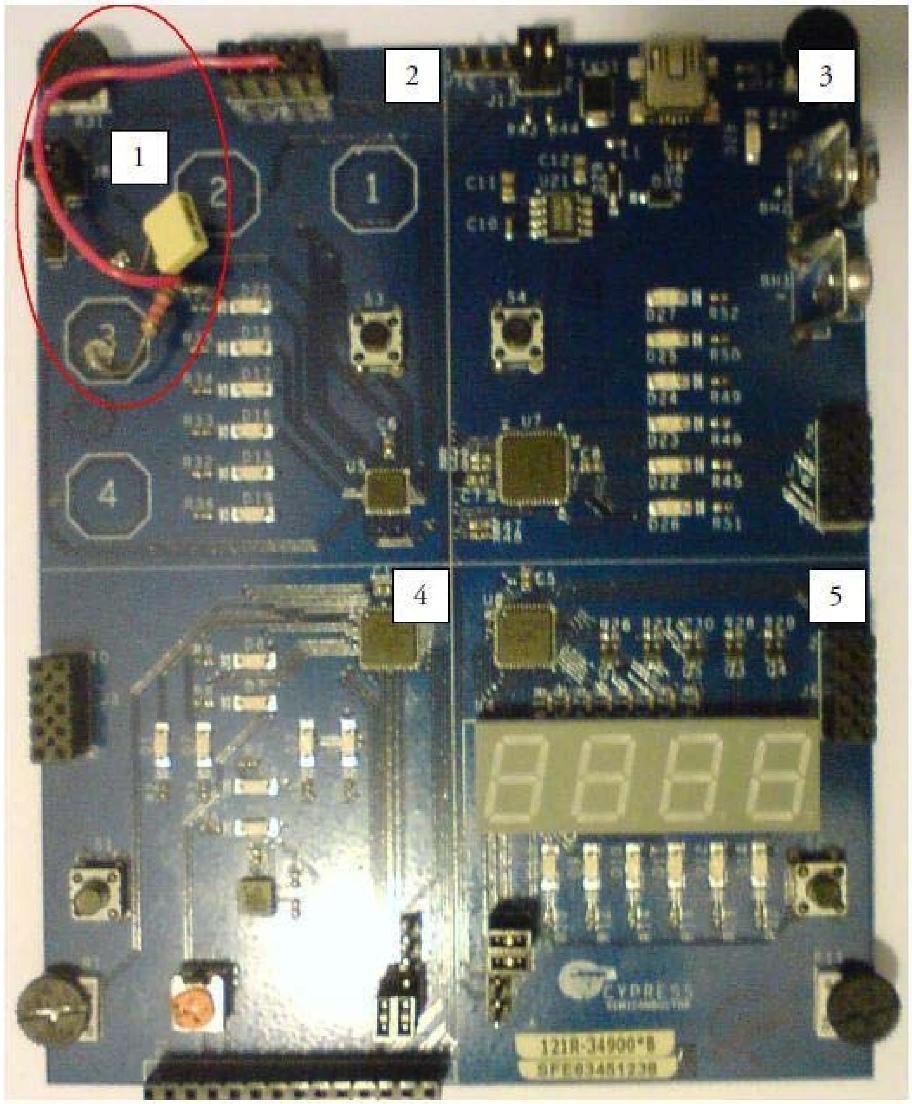

Figure 1 – Evaluation board used for the presented elaborations. (1.) Modification to enable the CSD method. (2.) Top left quadrant used for touch button applications. (3.) Top right quadrant used for communication applications. (4.) Bottom left quadrant used for gyroscopic applications. (5.) Bottom right quadrant used for LCD applications.

Appendix I – The EXTER Series

Figure 1 – EXTER series. (E1000 – Operatörspaneler, p.3)

Figure 2 – EXTER series viewed from behind. (E1000 – Operatörspaneler, p.4)

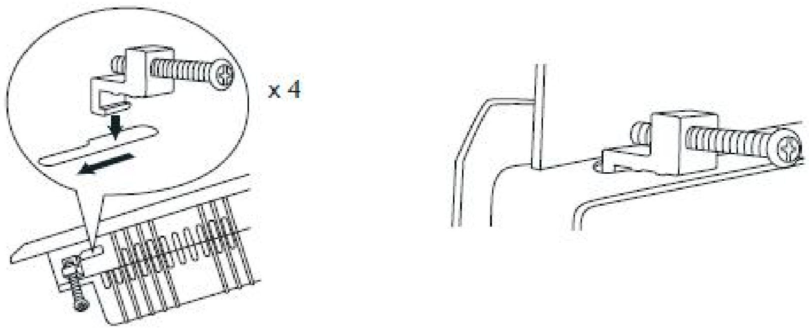

Figure 3 – Screw device used on the Exter series. (E1012 – Installation Manual (2007), p. 8)