NTNU
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Head-up display in driller and crane cabin

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Master of Science in Engineering Cybernetics
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Problem Description

Find and evaluate different Head-up display technologies
Build a pilot system

Use of head-up display in an operator s cabin on a drill rig, or in a crane, significantly improves the way of transfer information to an operator. The time and effort for an operator to get updated with the latest information is shortened. Another aspect is the time the operator s view is away from the process. This provides for an improved reaction time and increase safety compared to prior art. There are several head-up displays on the marked. Front projection, back projection, reflection and transparent displays are types of head-up display. Find the best integrate it into a pilot system.

Assignment given: 18. January 2010
Supervisor: Tor Engebret Onshus, ITK

PREFACE

This report is the work of a 30 credits master project in the last semester of the Engineering Cybernetics program at the Norwegian University of Science and Technology (NTNU). The report builds on my previous project report, which is a pre-study to this project. While I explored different head-up display technologies and chose a concept suitable of integration into a National Oilwell Varco (NOV) operator cabin in the preceding project, I have now focused on implementing a test system. The project has still been in cooperation between NTNU and NOV.

As described in the project report, NOV and I requested the company Planar Embedded to build two different transparent displays. Planar Embedded was positive, and sent us a demo unit to show the display quality. They agreed on a time window to deliver the first displays, and I started the process of making the control electronics. However, by the end of February, Planar Embedded suddenly and disappointingly went back on what they previously said and withdrew their offer to make the displays. This led to an unexpected change for me as well as for NOV. After discussing back and forth with my NOV supervisor Pål-Jacob Nessjøen, I decided to continue building the control electronics, but in a more general direction. The control electronics I finally ended up with can still be used with a Planar Embedded display, but a high voltage output buffer have to be added between the control electronics card and the display to make it work. To have something to prove the control electronics actually worked, I decided to build a five-digit display out of Plexiglas, transparent epoxy and 193 Light Emitting Diodes (LEDs). This test display is also an indication and an inspiration to what may be possible to make professionally, as I managed to make a fairly transparent display in my hobby workshop.

No one can say the very making of the test display hit the bull's eye when it comes to exploring the most advanced cybernetics. Nevertheless, I think this part was exciting as well, and I have learned quite a lot about plastics and resins. Also, I do think it is important to have an open eye for alternative solutions, even though they are a bit outside one's field of profession.

In the preface of the project thesis, I wrote that the complexity of a head-up display system collided with my idea of making a head-up display module from scratch. During this project, I certainly got to try making a complete module, although the system I have built is not ready to enter the market.

Even though it introduced quite a few problems, I do believe I have learned from the experience of Planar Embedded going back on what they promised. As far as I have heard, this is among those challenges one might encounter in real life, and preparations should be made to deal with situations like this before they happen. When looking back at the project, I suppose problems like these will be between the most important and useful experiences I will bring with me.

During the work on this project, I have got help and support from my excellent co-supervisor at NOV, Pål-Jacob Nessjøen. He could always be asked to hear out different solutions and thoughts, and has also been a great help in contact with different companies. My supervisor at NTNU, Tor Onshus, has also been very helpful.

Trondheim, June 15, 2010

Jonas Loe Kvalberg

ABSTRACT

This report describes the design and implementation of a prototype head-up display system, eventually to be installed in an NOV operator cabin. A head-up display is any transparent display being able to present information directly in the viewer's field of view. In many applications, this can improve working conditions as operators may have information presented more conveniently than with traditional displays. The report is based on a previous project thesis, which looked into different head-up display technologies, and made a conclusion on which one of them to implement in an NOV operator cabin.

Contact was established with a supplier of transparent displays at the end of the preceding project thesis. Their products seemed very promising to be integrated into a head-up display system. Therefore, cooperation was initiated towards delivery of custom made transparent displays in early 2010. Designing the display's driver electronics was decided to be the most important subject of this Master thesis.

This project has focused on designing driver electronics capable of controlling the professional transparent display, as well as a relatively transparent LED test display made as an additional part of this project. Development of software has been necessary in order to get the driver electronics to operate correctly. A PC program has also been made to remotely control the display, interfaced by a serial line.

Problems occurred at the supplier of the transparent displays, which resulted in no delivery of professional displays. The LED test display has therefore got the important role of showing in practice what may be expected of a professional solution, and to inspire NOV to go further with this project. There is no doubt a transparent display favorably can be introduced to an operator cabin, as it very likely can ease monitoring of important variables.

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1 Terminology

This section will give an explanation on terminology used throughout this report.

HUD	Head-Up Display; any transparent screen in the viewer's field of view
Eyebox	An area at least one of the viewer's eyes must be within to see all of the image of a projected HUD system
SPI	Serial Peripheral Interface
I2C	Inter-Integrated Circuit
HMI	Human Machine Interface
NOV	National Oilwell Varco
SWL	Safe Working Load
ADC	Analogue to Digital Converter
PCB	Printed Circuit Board
LED	Light Emitting Diode
OLED	Organic Light Emitting Diode
LCD	Liquid Crystal Display
API	Application Programming Interface
SCADA	Supervisory Control And Data Acquisition
MTTF	Mean Time To Failure

2 Introduction

This Master thesis is the second part of a project aiming to find and implement a head-up display solution in NOV operator cabins. The first part (1) looked into different head-up display techniques to be able to conclude on which technology to implement. This part describes the actual implementation of the technology chosen in the first part.

The report does not have an explicit theory part. Theory is introduced where it is presumed needed, rather than introducing all theory at once in one chapter. First, an introduction and presentation of the previous project will be given, including the application to which NOV wants to introduce a head-up display. The specific solution chosen in the first part of the project is introduced in chapter 3. The following chapters focus on the physical implementation, starting with the very display layout. Chapter 6 continues with describing the driver electronics and its requirements, as well as chosen key components. Software for the driver electronics, in addition to a computer program made to remotely control the display, is the contents of chapter 7. An evaluation of the prototype is done in chapter 8.

As this report is only focusing on a prototype and not a finished product, not much weight has been given the communication between the display and the control system of specific NOV operator cabins.

Below, basic properties of a head-up display system, as well as the specific application to which NOV wants to introduce a head-up display, will be presented. This is based on the work of the previous report (1).

2.1 Head-up display basics

A head-up display (HUD) is a transparent display that presents data directly in the viewer's line of sight. Because information is appearing directly in line of sight, the viewer is not required to look away from his or her usual viewpoint to get the information, as illustrated in Figure 2-1. Head-up displays are usually made either as a projector system creating a virtual image ahead of the reflected image, or by drawing an image directly at transparent solid state displays. Projected head-up display systems operate with a term called an "eyebox", which is an area at least one of the viewer's eyes must be inside in order to see the image.

In addition, the point of focus can usually be set to be ahead of the actual display, for example hovering above the front bumper on a car. This creates a virtual display (the real display will not be in focus), and significantly reduces the user's need to refocus between the road and the car's instruments; an operation a normal eye will need about a second to do (2).

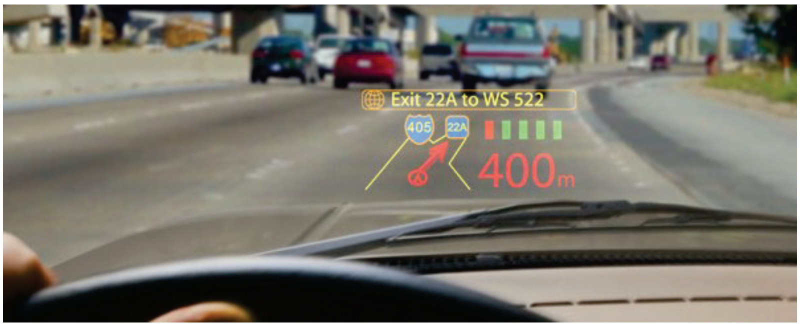

Figure 2-1: Head-up display in a car. Photo courtesy of Microvision Incorporated.

There are many ways to make a HUD system. However, not all techniques really qualify to be called *head-up displays*. This is mainly because such systems produce graphics at a real (transparent) screen, and not at a virtual screen focused somewhere ahead of where the "real image" should be.

2.2 Why install a head-up display?

Head-up displays are not very common. In fact, many are afraid having a head-up display in their application introduces an element of distraction and obstruction to sight, rather than being a helping tool. However, the successful introduction of head-up displays to an increasing number of applications should speak for itself. Today, for example, many family cars can be delivered with an optional HUD system.

One of the key elements with a HUD is to keep presented information clear and easily understandable. This means that replacing all indicators and screens with a head-up display, jamming all the information into the HUD, is quite an unwise idea. It should only present important and strictly relevant data, but at the same time provide an opportunity to browse through other variables and information. In other words, a HUD system is never to replace all other indicating devices, it should only be a clarifying addition.

Another advantage by having a HUD system is the viewer's reduced need to re-accommodate focus. This reduces stress on the viewer, and especially the viewer's eyes (3). As a consequence of this, ergonomic conditions are improved; an element of increasing importance.

An example illustrating the possible need of a HUD is based on experience by an NOV employee (4); crane operators are not in satisfactory control if they do not monitor both the hanging load as well as the instruments indicating important parameters. They have to frequently move their field of view, as well as refocus, to achieve this. A head-up display can ease this situation significantly.

2.3 The safety aspect

The immediate advantage by utilizing a HUD system is the ability to collect key variables and important information, and present it directly in the viewer's field of view. Another considerable feature is the improved safety aspect. A HUD system enables far more quickly recognition and action than a normal configuration, because imagery is presented within the visual accommodation of the viewer (5), (6). For example, alarm messages can be produced directly in the field of view, maximizing the chance of detection at an early state. When the viewer looks at instruments in a head-down configuration, he looks away and may not see an external event needing immediate attention and action.

2.4 About the specific application

A part of NOV's line of products and services is production of driller and crane cabins, including the control systems and Human Machine Interface (HMI). As the market evolves and customers are expecting a more ergonomic control interface, NOV is looking into new ways of presenting information to operators. Using a head-up display is one of the ideas, and it was the motivation for exploring different HUD techniques in the preceding report. However, a HUD system must fulfil certain demands to be attractive, no matter which technique used. Important features are:

- Sufficient brightness, even in direct sunlight
- Easy to read and understand text or graphics presented on the display
- Large eyebox / large viewing angle
- Adjustable luminance/contrast to be able to compensate for varying ambient light conditions. For example, it has to be possible to reduce display brightness when used at night
- Preferably more than one colour
- Must not get in the way of the operator, which would quickly make it a source of annoyance
- Easy to install, both in a new cabin and in an existing one
- Reasonable cost vs. features
- Low and easy maintenance

Figure 2-2 shows an example of a possible way to install a projected HUD system onto an NOV workstation. Because the operator's chair may turn, the projector and combiner have to be attached to the very chair in order to keep the HUD's eyebox at the same place related to the operator. This also means a dedicated combiner is necessary. Using the windshield as a combiner, as done in cars, will force the operator always to sit at the same place, unable to turn the chair.

Figure 2-2: Example of a possible way to install a HUD, compared to the existing solution of the same workstation. The HUD can replace one or more LCD screens, or be a useful addition to the HMI. The lifting mechanism is used to raise the combiner and ease entering of the workstation (7).

The workstation itself and the fact that it can turn, complicates possible implementations of a HUD system. In addition, the operator is very often required to look up or down and to the sides out of the cabin, and by that looking out of the eyebox of the HUD. In other words, making a practical and durable projected HUD system represents a major engineering challenge.

Another approach to a projected HUD is to attach transparent displays onto the windows. Since these displays have a much lower cost than a projected HUD module, it is possible to apply several displays at the same application, within the same economic limits. The lack of the projected HUD's collimated graphics (focused at infinity) can to some extent be compensated for by making graphics large and simple. See Figure 2-3 and Figure 2-4 for examples of typical NOV control cabins.

Figure 2-3: Multi-purpose control cabin by NOV.

2.4.1 Operating conditions

Even though the HUD system is to be installed offshore, it will always be inside a temperature controlled cabin. This means there are no excessive requirements regarding temperature, humidity, explosion hazards or vibration levels (8). Direct sunlight us probably the most extreme condition a HUD system will meet. However, as with all industrial equipment, it is desirable with a robust, long lasting system. In more professional terms; a high numbered MTTF.

Figure 2-4: Driller's cabin by NOV.

2.5 Conclusions of the previous project

Several HUD technologies were discussed, whereas two strong candidates appeared. One solution utilized a laser projector in combination with a reflecting glass plate in order to draw a virtual image in front of the actual reflecting plate (see Figure 2-2 for an example of a possible way to install such a system). This is a very elegant solution, but strict requirements to placement and a small eyebox made NOV sceptical to this solution in this specific application.

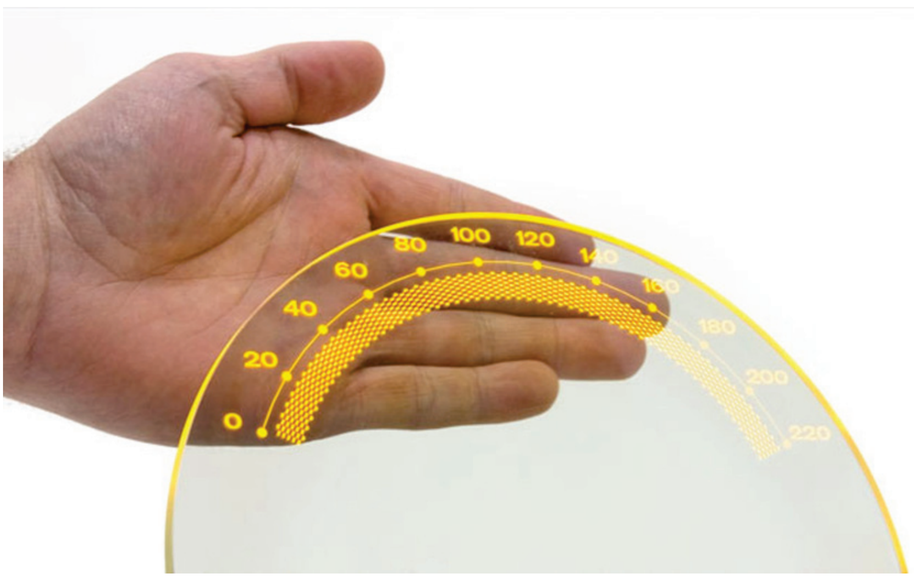

Figure 2-5: Example of a transparent display. Photo courtesy of Planar Embedded.

The other solution presented was a transparent electroluminescent display from Planar Embedded. An electroluminescent display can look very much like an LCD display, but unlike the LCD which only filters a constant backlight in order to create an image, the electroluminescent display elements emit light by themselves. Electroluminescent display elements can be made almost completely transparent when powered off. Se Figure 2-5 for an example of a transparent electroluminescent display.

Due to availability, image quality and price, an electroluminescent display from Planar Embedded ended up as the preferred solution. This solution has the disadvantage of creating an image at the actual screen, and not a virtual image ahead of the screen. This means the operator will not experience one of the key benefits of a "real" head-up display system; the reduced need to re-accommodate focus from the background to read the display. By use of large graphics however, this effect can be reduced.

By the end of November 2009, contact was established between NOV and Planar Embedded with the purpose of getting hold of transparent displays in early 2010. Several e-mails were exchanged and telephone conferences arranged in order to get a clear impression of what Planar Embedded could supply, as well as for them to understand exactly what NOV wanted. Planar Embedded sounded optimistic, and stated they would be able to produce a display in roughly six weeks time. However, to try and reduce the production time, it was decided that the design and production of the control electronics would be taken care of by NOV, in terms of this Master thesis.

3 Custom made display by Planar Embedded

As described in section 2.5, Planar Embedded was engaged to produce custom transparent displays based on NOV's design. These displays are based on electroluminescence, meaning that the display will emit light itself, rather than filtering a constant backlight like done in for example a Liquid Crystal Display (LCD). The graphics on each display are made by turning on distinctive, pre-defined segments, which are all transparent when powered off. Having defined distinctive segments gives the benefit of clear and bright graphics compared to pixel based displays. For a more thorough explanation, see the preceding project report (1).

3.1 About transparent electroluminescent displays

There are two ways in which you can achieve electroluminescence; intrinsic and charge injection (9). Charge injection is the technique used in an LED, where a current is passed through a semiconducting electroluminescent material in order to generate light. Electroluminescent displays are intrinsic electroluminescent. In this technique on the other hand, the light is a function of an electric field, not a current.

The electric field of intrinsic electroluminescence is created by conducting plates on either side of an electroluminescent material (usually phosphor). These plates can be made almost completely transparent to achieve optically transparent displays. Electrons are accelerated by the field set up by these plates, exciting electrons in the electroluminescent material as they collide. When the electrons recombine, they release their accumulated energy as photons – illumination (10). To sustain constant illumination and not only a short pulse of light, an alternating voltage is applied to the conducting plates (11).

This alternating voltage makes control of such displays different from many other displays, for example LED or LCD displays, which can both maintain their graphics when a low constant voltage is applied. Transparent displays by Planar Embedded require about 200 V to work properly. The brightness is controlled by varying the frequency of the applied voltage, peaking at about 60 Hz. Because each change in the voltage generates a short pulse of light, the brightness is roughly proportional to the switching frequency.

Due to its solid state structure, the display is very rugged and deal very well with vibration and wide temperature ranges. It maintains its rated response time of 1 ms throughout the entire temperature range (-50 to 85°C).

3.2 Planar Embedded demo unit

As an example of what Planar Embedded could deliver, they offered NOV to have a look at their demo unit in the start of the cooperation process. The demo unit was basically a digital clock, using a transparent electroluminescent screen made by Planar Embedded to show the clock digits. The demo unit can be seen in Figure 3-1.

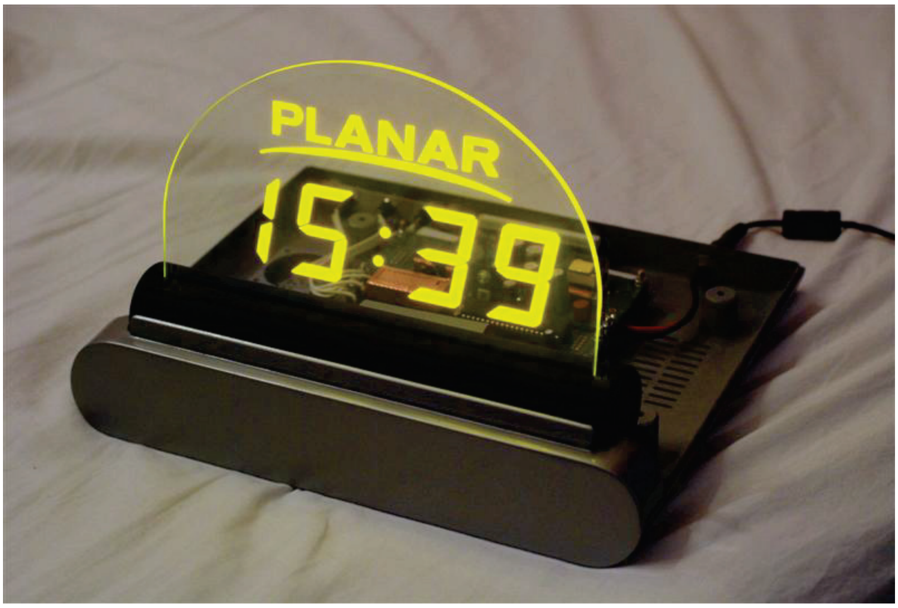

Figure 3-1: Planar Embedded demo unit

The demo unit was a success in terms of getting an idea of what a finished product could look like. Both brightness and contrast were very good, making the digits easy to read, even in direct sunlight and against very bright backgrounds. As described in the project thesis (1), the screen is made by gluing an electroluminescent layer between two pieces of glass. The yellow glare along the sides of the screen comes from this electroluminescent layer, because not all of the light is transferred out of the glass, but reflected between the surfaces. However, this glare can easily be reduced by applying a thin layer of non-transparent paint along the sides.

3.2.1 Inside the demo unit

As a source of inspiration, the unit was disassembled to get a closer look at the driver electronics. Figure 3-2 shows the inside of the unit, with the power supply at the bottom half, and the microcontroller / driver board at the top. Below the two circuit boards, which is impossible to see on the figure, are buffer circuits which enables the low voltage logical levels of the microcontroller to control the 200 VAC segments of the display.

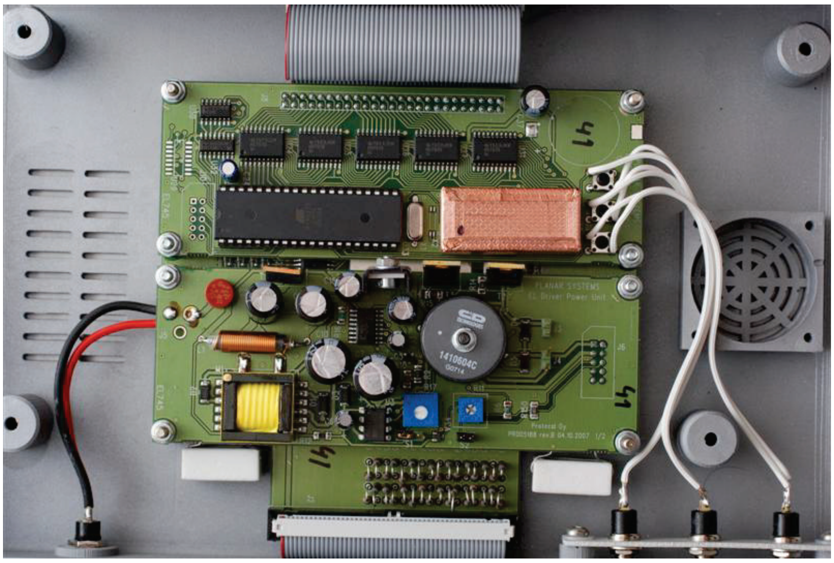

Figure 3-2: Demo unit driver electronics

The power supply of the demo unit is a step-up switch-mode power supply, converting a 12 V input to about 200 V, 60 Hz, which is the voltage required for the display segments to illuminate properly.

Planar Embedded has made the demo unit in different modules. The power supply is a universal developed by Planar Embedded for many of their products. To save time in completing a prototype, NOV requested to buy these pre-fabricated power supplies from Planar Embedded, as they are powerful enough to support the larger displays wanted by NOV.

To save time, it was decided to make the driver electronics of this thesis in a similar manner. However, as the number of I/Os is planned to greatly increase for the NOV display, the control electronics has to be more comprehensive.

4 Prototype display

4.1 Prototype requirements and goals

The motivation for making a prototype was to get a proof of concept; a working model to evaluate in real life applications. In addition, a screen working as a head-up display would undoubtedly have caught positive attention in NOV's favor from customers and at gatherings and exhibitions.

Because NOV is constantly at search for new ways of modernizing the HMI of their operator cabins, looking into techniques of doing head-up displays is a natural step. Higher efficiency, operator ergonomics and security are reported benefits from other applications featuring a head-up display (5). To actually get hands on a HUD prototype is important to get an impression on how costumers react to this new piece of hardware, and to investigate if there really is a marked for this type of interface.

4.2 Development from prototype initially proposed

At the end of the project report, the following figure was presented, showing two different outputs from the same proposed display layout.

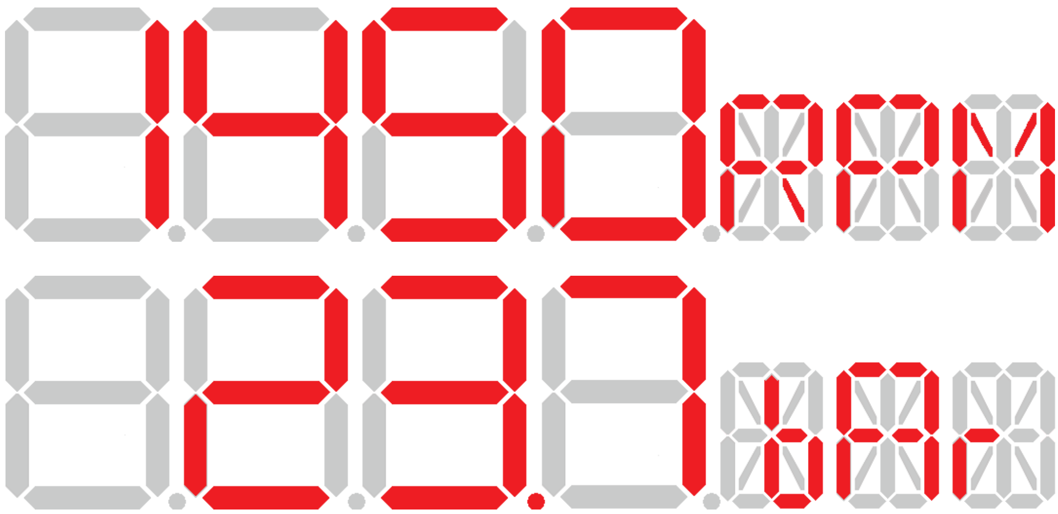

Figure 4-1: Example of custom transparent display layout. Two different outputs are shown. Grey areas (turned off segments) will be transparent on a live model.

After a period of contact with Planar Embedded, this layout was gradually changed into a similar, basic layout, and a more advanced one. These can be seen in Figure 4-2 and Figure 4-3 in the following section.

4.3 Final transparent display design

Planar Embedded was requested to make two different screens. First a very basic one to get a proof of concept, and later a more advanced. The two different display solutions can be seen in Figure 4-2 and Figure 4-3. As seen in the figure, the basic display can only show one numerical value at once. The larger areas are transparent when turned OFF. When turned ON, they can be used to highlight values or units engraved or written at the glass over the areas. This enables a single display to fit many specific applications. In this way, the display can cycle through different values, indicating the current value by highlighting it. This basic display is therefore a very flexible solution, and can be used in any application in the need of displaying information to the operator.

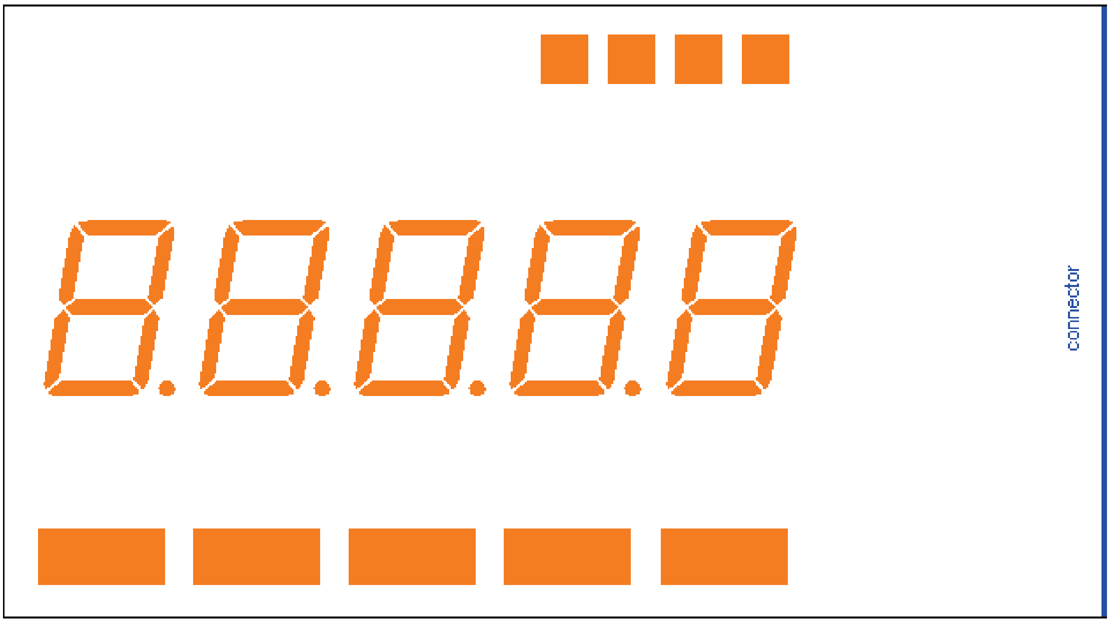

Figure 4-2: Basic display design

The advanced display is made in cooperation with NOV's department in Molde, which is specializing in offshore cranes. Compared to the more basic screen in Figure 4-2, it can display three important variables of a crane operation at once; hook load, radius between center point of the crane and the hook (the length of the lifting arm), and safe working load (SWL). Obviously, SWL will change by varying the radius, so an additional bar graph has been added at the left side of the display, showing the influence the combination of hook load and radius has on the SWL dynamically. In addition, a few special indicators have been placed on the display; the NOV logo, an alarm sign, and two symbols indicating if the hook is above deck or the sea.

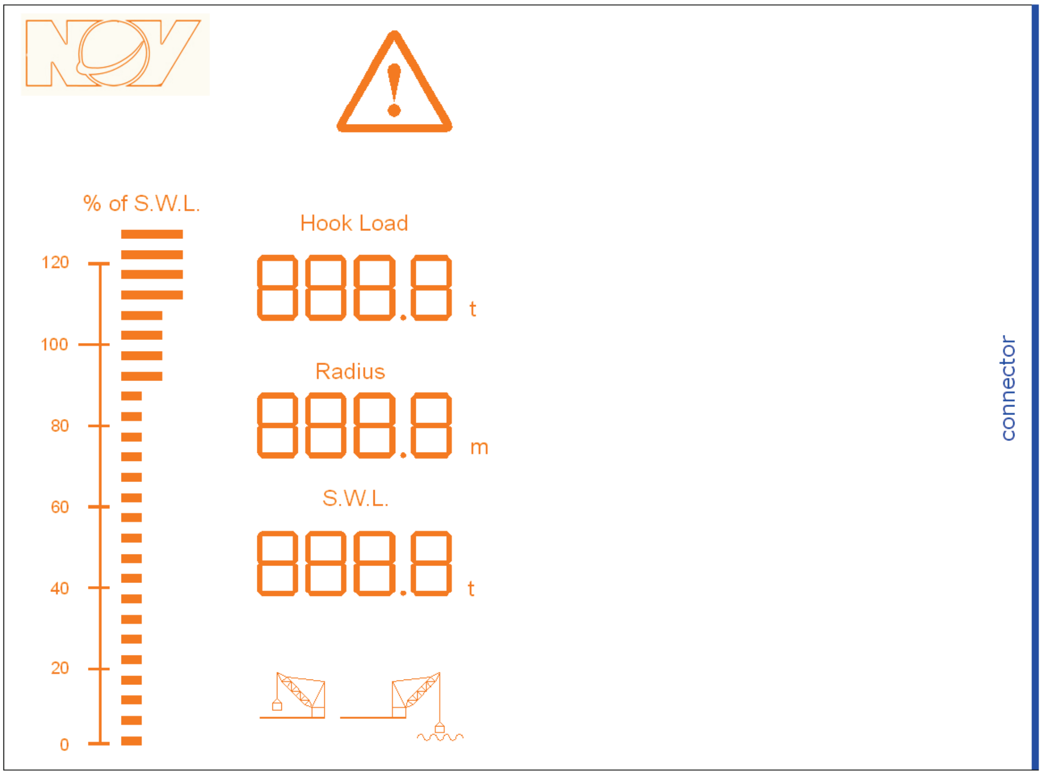

Figure 4-3: Advanced crane operator panel

As seen on the figures, each panel has a connector to the control electronics on the right side. This enables the panels to be mounted to the frame on the right side of the windshield, hopefully reducing non-transparent parts to be "hidden" by the metal window frame of the cabin. The transparent part of the panels between the connector and the graphics are designed to get the graphics as far away from the connected control electronics and into the field of view as possible, as the control electronics is not transparent. In a finished product, the control electronics should be as small as possible so that it can be mounted on the window frame, obstructing as little of the sight out of the cabin as possible.

5 LED test display

As a last minute compensation for the highly unexpected undelivered professional display, it was decided to build a transparent test display from scratch. Because this display is made by hand in a hobby workshop, it is not completely transparent. However, the purpose of the display is to get a proof of concept, as well as illustrate what might be possible professionally, compared to what is possible to achieve by hand in a hobby workshop.

Creative approaches had to be made in order to get a concept both possible to realize and at the same time fairly transparent and able to emit light by itself. In the start of this process, different light sources were considered. The light sources were intended to be used to form numeric indicator segments to get a display resembling the basic display design by NOV, as seen in Figure 4-2.

5.1 Display components

After testing different ideas, Plexiglas turned out to be a very good base for the display. The light sources could then be glued on top before being embedded in a transparent casting. There are not many good ways to make bubble free transparent castings without advanced equipment, like a vacuum chamber. To achieve that, the mixture has to be of low viscosity in order to let air bubbles escape to the surface. In addition, the casting has to be as optically clear as possible. Unfortunately, the search for suitable products in Norway was unsuccessful.

However, a very promising product was found in USA, by the company *Epoxies Etc…*, which is specializing at different epoxy-based chemicals. They had a product specially designed for optically clear castings, with very low viscosity (12). After contact via e-mail, they offered a free sample quantity of 500 ml, which was just enough.

5.1.1 Light sources

There is no problem finding different light sources to make display segments. The problem is to make them as transparent as possible when turned off, and to connect them, either optically or electrically, to the control unit. Optical fibers and electroluminescent wire were considered, but found too complicated to install and to look good. The only real option for light sources turned out to be miniature LEDs. LEDs are small semiconducting devices which emit light when current is passed through their semiconducting materials as briefly described in section 3.1. Because they have diode characteristics, they only let current pass through them in one direction.

Everlight subminiature LED

This LED is a mix between surface mounted LEDs and standard through-hole mounted LEDs, see Figure 5-1. Five of these LEDs soldered in series will make a sufficient size for an indicator segment. The LED has two important features which makes it interesting:

1. It has legs. This makes assembling easier, but more importantly; they are very short and to the sides, not expanding out of the back of the LED. This opens the possibility of soldering each LED directly to its neighbor, without any additional wiring. In addition, the side mounted legs reduce the total building height of the display.
2. The LED casing is made in transparent epoxy, which makes the body and lens almost invisible when later encapsulated in transparent epoxy.

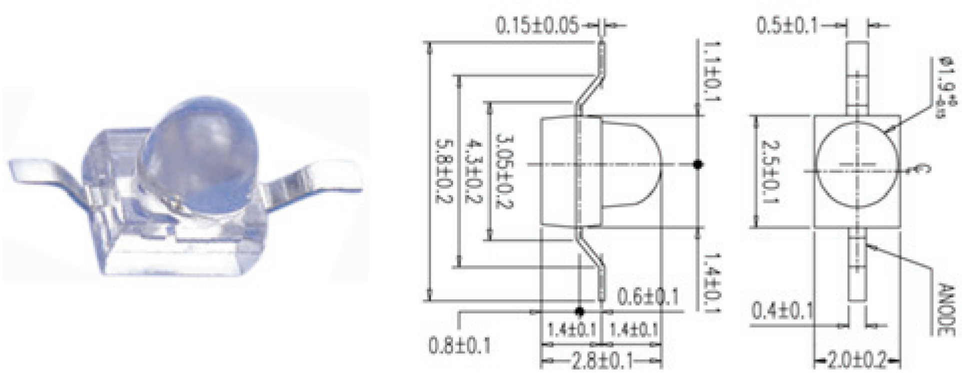

Figure 5-1: Everlight subminiature LED(13)

The LED has a rated forward voltage of 2.25 V, when the maximum current of 25 mA is passing through.

5.2 Building the test display

As described in section 5.1.1, each numeric segment is made out of five LEDs. Green light is chosen for the numeric segments. They are soldered directly to each other and connected using very thin coated copper wire. Each segment is then fixed on Plexiglas to form five seven-segment indicators. In addition, three comma segments and a red-orange alarm sign were added, as seen in Figure 5-2 and Figure 5-3. Combined, this results in the following number of LEDs:

Segment size: 5

	Segments	**LEDs**
Five seven-segment numbers	35	175
Alarm sign	3	15
Commas		3
Total number of LEDs		**193**

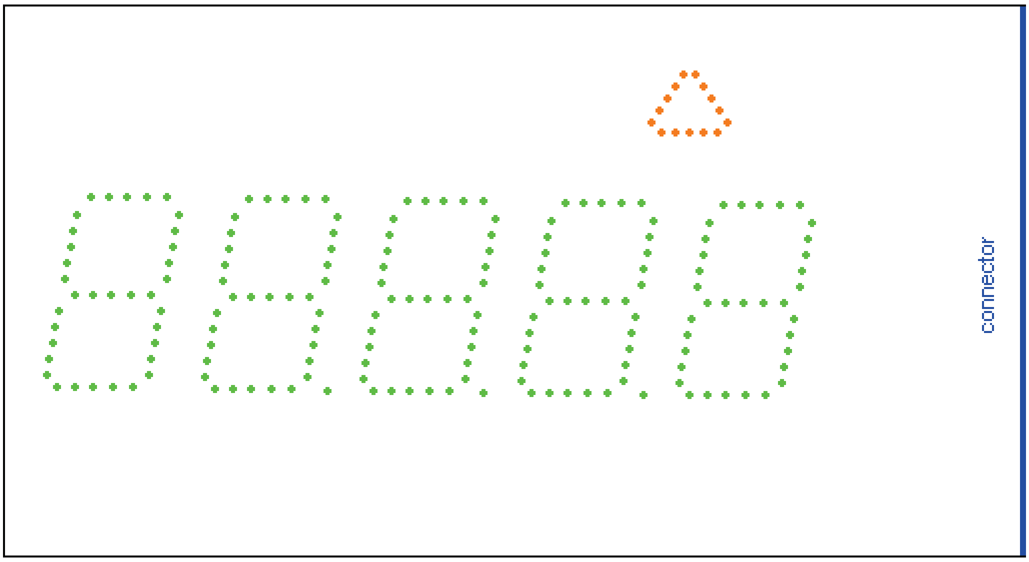

Figure 5-2: Test display

A single LED might seem like a negligible power consumer. All LEDs combined however, makes this look a bit different. Total power consumed by the display will be:

$$193 \text{ LEDs} \times 25 \text{ mA} \times 2.25 \text{ V} = 10.86 \text{ W}$$

This is a significant amount of power, and most of it is dissipated as heat by the LEDs. Getting the heat transferred out of the display could be a problem because there is no air circulation around the LEDs, but due to satisfactory heat conduction properties of the epoxy, it should work out fine.

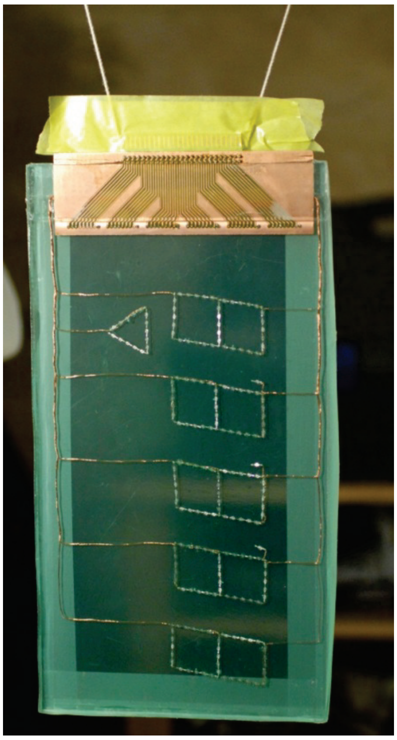

Figure 5-3: Test display, masked and painted.

All cobber wires are terminated at the connector board at the right side of the display in Figure 5-2. When all components were positioned carefully, epoxy was poured over the Plexiglas, sealing every component inside an optically clear casting. Thermoplastic adhesive from a glue gun around the edges of the Plexiglas was used to form a casting mold preventing the epoxy from escaping before it cured. These were later cut off to get smooth edges.

Although the epoxy was supposed to cure and harden, the surface of the display stayed very vulnerable. The surface was easy to damage, and it got quite a few scratches and marks during the period of testing the complete system. To try and salvage the surface and make it harder, it was first sanded down using very fine P1200 sand paper, before applying a total of seven layers of clearcoat. This sealed the surface and made it hard and durable. Figure 5-3 shows the display after the clearcoat is applied.

Even though the display seemed very transparent at first sight, the damages of the epoxy cast and the addition of clearcoat made the surface slightly uneven. This is not easy to see when looking through the display at close objects (see Figure 5-6), but when looking through the display at distant objects, these small imperfections result in small lens effects which diffract the light and cast a light blur on the background.

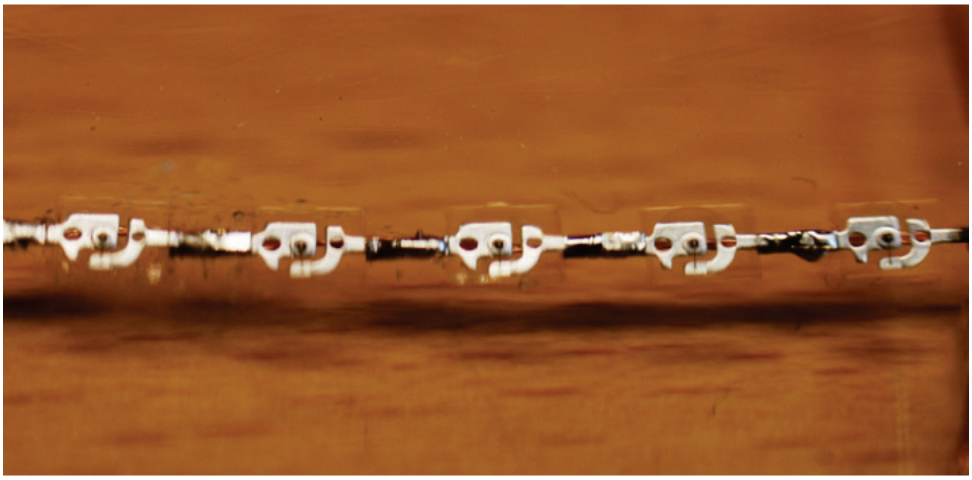

Figure 5-4: Close-up of a five-LED embedded indicator segment. The segment seems to hover in thin air above the wooden desk, but is actually resting at the Plexiglas base and is completely covered in the epoxy.

Although the very lens and body of the LEDs nearly vanished in the epoxy, the electric terminals of each LED, the soldering and the wiring are still visible. This however, was predicted. Professionally and with more time, such screens should be possible to produce almost completely transparent. For example, the actual emitters (the semiconductor dies) of the LEDs can be made and assembled in finished segments of the right shape, without the need of their own epoxy body or metal terminals. As for the test display, the metal terminals are far more visible than the miniature emitting dies connected between each LED's terminals. Figure 5-5 illustrates this with close-up photos of LEDs embedded in the test display. Imagine how transparent the display would be if the very emitters were embedded in the epoxy directly.

In addition, it is possible to produce almost invisible leads to replace the thin copper wire used when assembling this display. For an example of this, look at the demo unit provided by Planar Embedded in Figure 3-1. All the glowing segments have electrical leads connecting them through the bottom of the glass panel to the control electronics.

How the display looks like when operated in real life will be presented in chapter 8.

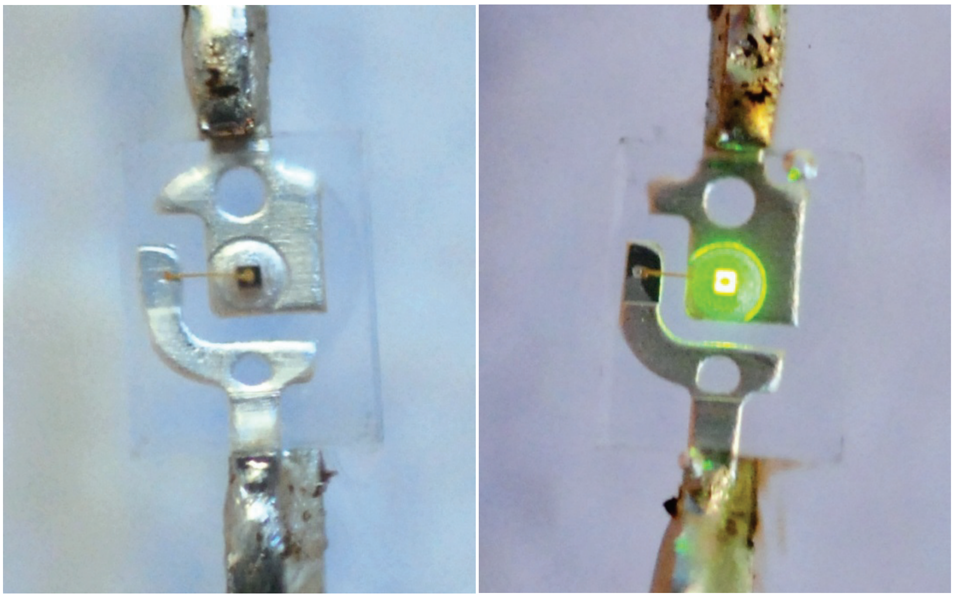

Figure 5-5: LED close-up. The semiconductor die is the little black square on the picture to the left, which is glowing on the picture to the right. Observe how the LED bodies are nearly vanished in the epoxy casting. To get an impression of the proportions, keep in mind the bottom leg of the LEDs is 0.4 mm wide.

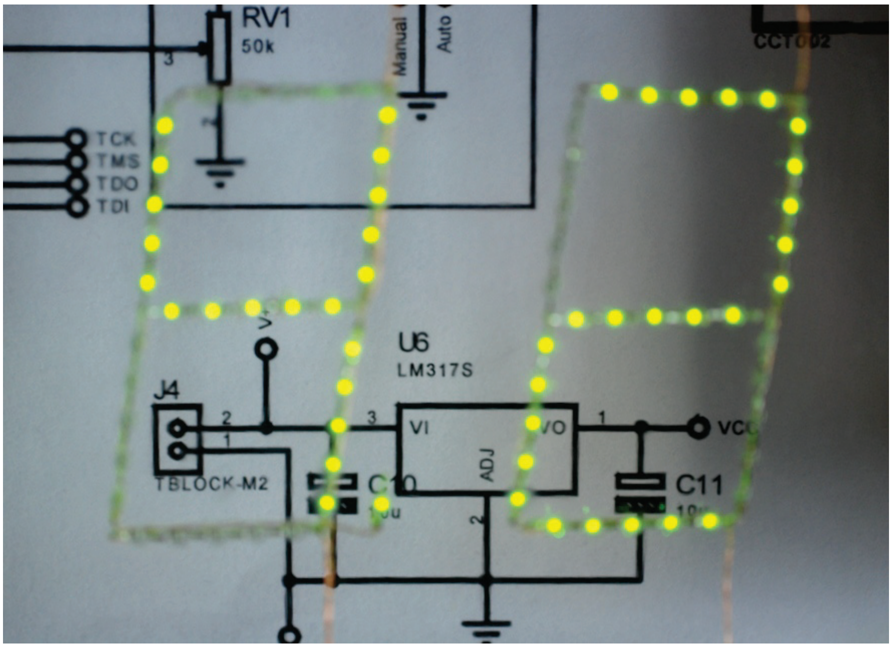

Figure 5-6: Example of the transparency of the LED test display. The display is resting on top of a printed piece of paper.

6 Prototype electronics

As a result of the change in the project when Planar Embedded could not deliver displays after all, it was decided to continue using as much of the planned electronics as possible. Two designs have been made, although they both are based around the same control structure and peripherals. One for the 128 segment advanced display proposed by NOV, complete with high voltage output buffers, and one for the basic 48 segment display. This second design is made without the high voltage output buffer, because it was chosen to build an LED test display from scratch to get some sort of replacement for the professional display. Since this test display has segments made by low voltage LEDs, it is not necessary with a high voltage buffer. However, an output buffer can at a later time easily be fitted between the control electronics and the display to support the basic electroluminescent display, as they are connected using a standard connector. The LED test display is described in section 5.

The electronics is designed in Proteus ISIS 7 for schematics and ARES 7 for circuit board print layouts.

6.1 Design overview

As described in the preceding project thesis (1), electroluminescent displays from Planar Embedded require a voltage of about 200 VAC to work properly. The brightness is controlled by varying the frequency, peaking at about 60 Hz. This means the control electronics for the electroluminescent display must be able to handle high alternating voltages, which is impossible to control directly from a microcontroller or a standard display/segment driver.

Figure 6-1 illustrates the main components of the system.

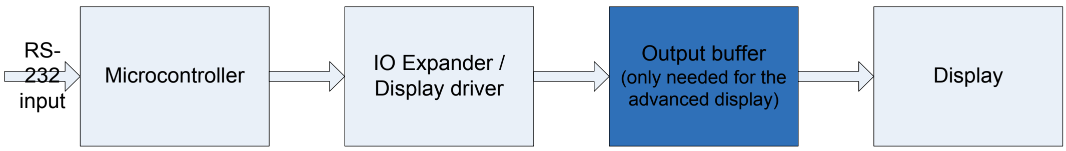

Figure 6-1: Block diagram, control unit and display

6.1.1 The control unit

The purpose of the control unit is to receive data from a remote computer, and through a set of driver circuits control the very segments of the display. In this project, the communication will be via RS-232, although Profibus DP is widely used by NOV in their operator cabins. RS-232 is practical as this is a very common and easy to implement standard.

The control unit will be built around a microcontroller with necessary peripherals to be able to communicate via RS-232. Multiplexing or I/O expanders will be used to be able to control all necessary display segments from a single microcontroller.

6.1.2 The output stage

The purpose of the output stage is to drive many display segments in an efficient manner, preferably from few microcontroller pins.

For the advanced display driver electronics, the output stage is also a link between the low-voltage control electronics and the high voltage display. After some researching, it was decided to use photovoltaic relays to buffer the low voltage control electronics, to get an output stage capable of controlling high alternating voltages. Photovoltaic relays were found suitable because:

- They have a solid state structure, which means no moving parts
- Can handle high switching frequencies
- Can handle high output voltages
- Galvanic barrier between input and output

In other words; in addition to ensure a capability of high speed switching of AC load voltage, it intrudes an optical barrier to protect the low voltage parts from the high voltages. Photovoltaic relays are described more in section 6.4.1.

6.2 Controlling of the display segments

This subsection will look into two different ways of controlling many outputs from as few pins as possible of a microcontroller.

6.2.1 Multiplexing

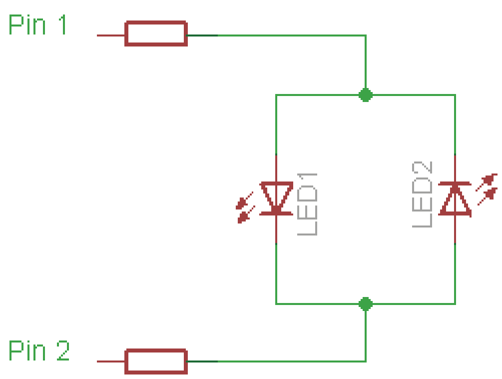

Figure 6-2: Complimentary drive

An elegant solution to reduce the number of outputs needed to control a display is to multiplex the outputs. Charlieplexing is a type of multiplexing specially intended for LED-displays (14) (15). It utilizes the tri-state logic of microcontroller pins, which means setting the pin-state of the microcontroller to 0, 1 or X. These values are usually represented by 0 V, 5 V and setting the pin to input (high impedance) to represent “not connected”. This strategy becomes very useful when LEDs are coupled in complementary pairs, as seen in Figure 6-2.

This enables both LEDs to be individually controlled by the two microcontroller pins, depending on which way the voltage is biased over the LEDs. Because of the diode properties of LEDs, they only enable current (which generates the light) in one direction.

When a complimentary pair is coupled between all possible pin configurations from the controller, the resulting matrix, see Figure 6-3, is said to be Charlieplexed. There is, however, a minimum requirement in the forward voltage of the LEDs. For the technique to work as intended, the total forward voltage of two LEDs in series must be greater than logical 1 from the controller. If not, LEDs supposed to be OFF might glow more or less. The relationship between the number of pins required and the number of LEDs possible to control will be: for n controller pins, you can drive $n(n-1)$ LEDs (14).

Obviously, not all the LEDs in the matrix can be lit at the same time (Figure 6-2 illustrates a basic example of why, because each LED require the opposite biasing than the other in order to light up). But as with other techniques of multiplexing, the LED matrix can still form an impression of a static image by fast enough flashing each LED scheduled to be ON sequentially and repeatedly. A refresh rate for each LED of 50 Hz or more is necessary to avoid visible flickering (15).

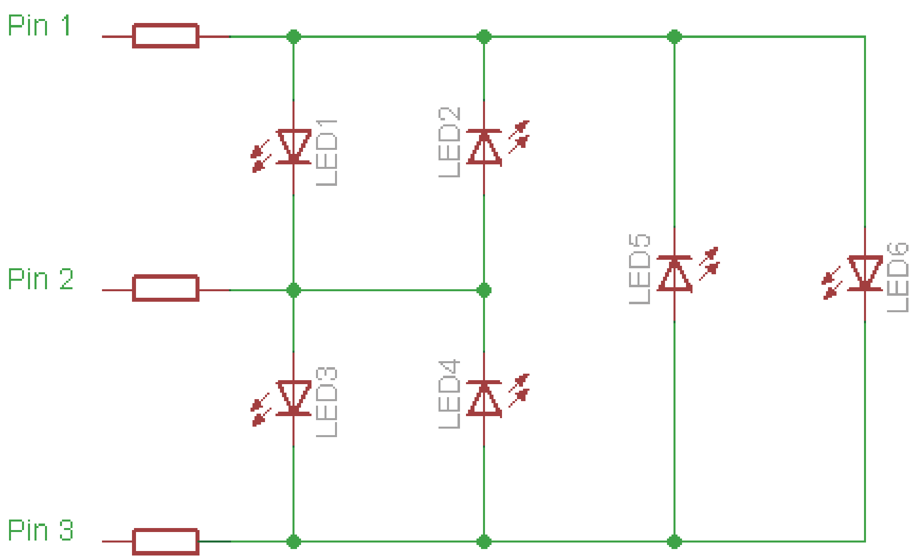

Figure 6-3: Three pin Charlieplexing

The fact that only one LED can be lit at once introduces a problem in terms of reduced duty cycle. Because each LED only flicker, not constantly glow, the short flicker must be proportionally more powerful with the reduction in ON-time in order to appear to be of the same brightness as it would if it was constantly glowing. In other words, the peak current through each LED will increase with an increased number of Charlieplexed LEDs. An LED has a maximum peak current limitation as well as an average, and this effectively reduces the practical size of a Charlieplexed display.

As mentioned earlier in this section, Charlieplexing can only be used with segments made by diode elements. A fundamental part of this technique is the fact that different segments will light up depending on the polarity of the supplied voltage. The segments must have diode characteristics, which the electroluminescent display has not. The electroluminescent display elements light up by applying an alternating voltage, and not by a specific current direction. See section 3.1 for more details on this. Because the project got a sudden change when Planar Embedded announced they could not make any transparent displays for NOV, Charlieplexing could have been a very good technique to control the LED test display described in section 5. However, it was decided that the driver electronics should still be able to control displays from Planar Embedded in the future, and therefore must support a dedicated control line per display segment.

6.2.2 Port expander

Few microcontrollers have enough I/O pins to be able to drive all necessary segments directly. And even though they can be found, the accumulated amount of current sourcing or sinking would very likely be too high for the microcontroller. An easy solution to this is introducing a port expander. This is basically a serial to parallel converter, enabling additional I/Os to be connected to the controller via a serial interface, usually Serial Peripheral Interface (SPI) or Inter-Integrated Circuit (I2C).

There are a lot of different port expanders on the market. However, in this application the port expander only needs to provide outputs, as it is only intended to drive the display segments. The segments are all passive, so a possibility for the port expander to send data back to the microcontroller will be of no use. To get a driver electronics board compatible with both the LED test display as well as the inputs of the photovoltaic relays of a possible high voltage display's output buffer, a natural option is to choose port expanders optimized for driving LEDs. These often have current regulated outputs, which will ensure safe operation of both LEDs for the test display and the photovoltaic relays for the high voltage electroluminescent display, even without any change in software or hardware of the controller board[1].

[1] Based on the assumption that the LEDs of the photovoltaic relays can handle the current set for the LED segments of the test display.

6.3 Driver electronics for the LED test display

These schematics are designed without the high voltage output buffer necessary to be able to drive transparent displays by Planar Embedded. This decision was taken based on the fact that this is a prototype and only intended for the LED test display. However, as the driver electronics is connected to the LED test display by a standard connector, a high voltage output buffer can easily be connected in between at a later point. The schematics can be found in appendix B.

6.3.1 Main components

This section describes the most important components of the control electronics design. Surface mounted components are preferred. For a complete list of components, see appendix A.

Microcontroller

Tools and components from Atmel are easily available at NTNU, and because there is a lot of experience with these products at NTNU, Atmel is a natural supplier of microcontrollers for many student projects.

Due to previous experience with the ATmega128 microcontroller, it was chosen for this project as well. This is a high performance 8-bit microcontroller with JTAG-interface which can be used to program the unit, as well as enabling real-time debugging, a useful feature during development. If this design was to be mass produced, the microcontroller decision might have been different. For example, the ATmega128 has a lot more capability in terms of both processing power and free I/Os (when combined with a port expander) than what is necessary here. The system clock is synchronized by an external 4.9152 MHz crystal oscillator.

Port expander

As mentioned in section 6.2.2, port expanders with regulated current outputs were especially interesting in the process of choosing components. The STP16CPS05 from ST Microelectronics is connected via SPI (SPI is described in section 7.3) and is a 16-bit constant current LED sink driver, with the possibility of adjusting the output current through an external resistor, from 5 – 100 mA. As the outputs are current regulated, the supply voltage is not critical. The unit will by itself adjust the current to the right level, independent of the supply voltage. Three of these will give 48 outputs, and are enough for the test display as well as the basic display by Planar Embedded. It comes in the small TSSOP24 package. Many of the advantages of this chip are listed below:

- SPI interface
- Possible to operate in cascade
- High output voltage, up to 20 V
- Low supply voltage
- Can handle 16 separate 100 mA outputs, a sinking capacity of 1600 mA combined
- Adjustable, current regulated outputs
- Small package
- Can handle the LEDs of LED test display directly as well as the photovoltaic relays intended to use with a possible Planar Embedded displays
- Low price

Based on these advantages, deciding on this device was easy. Figure 6-4 shows a typical application schematic of the LED driver.

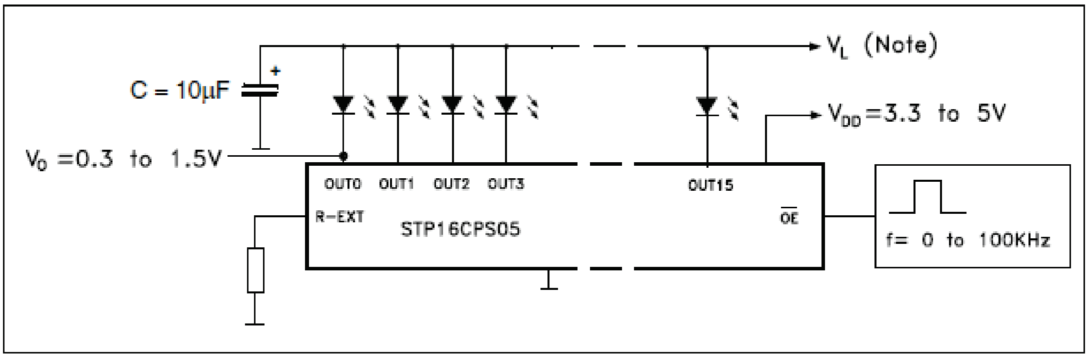

Figure 6-4: Typical application schematic, STP16CPS05 (16)

The LED drivers communicate as mentioned via SPI and have pins for serial *data in* and serial *data out*. The *data out* pin is practical when more outputs are needed; the *data in* of a new LED driver can just be connected at the serial *data out* of the preceding, without the need of slave select logic controlled by the microcontroller. More details on how the device operates and works are described in section 7.4.

RS-232 interface

The RS-232 input is intended for controlling of the display from a computer or a control system, for example the control system of an NOV crane operator cabin. An external RS-232 driver has to be added because the ATmega128 cannot reach the voltage levels required by the RS-232 standard (17). In addition, the RS-232 driver provides improved protection against short circuits and high voltages.

A standard RS-232 driver was chosen; the surface mounted MAX232DG4 from Texas Instruments. It can communicate over the USART-interface of the ATmega128, accessed through RXD0 and TXD0 of the microcontroller. Even though the RS-232 driver's supply voltage is 5 VDC, it has to be able to provide voltages between +15 and -15 V to meet the specifications of the RS-232 standard. This is achieved by connecting four external 1uF capacitors, which the unit uses to increase its output voltage.

Manual inputs

The manual inputs include a three-state selection switch, a potentiometer, and a reset switch. The slider of the potentiometer is connected to PF0 on the ATmega128, which has analogue to digital converting (ADC) capabilities. As the other pins are connected to ground and via a resistor to VCC, the potentiometer acts like an adjustable voltage divider, which by the ADC is converted to an integer ranging from 0 to 255 (8-bits). Based on the state of the selection switch, this integer can be used differently by the software. See appendix B.1 too see how this is connected.

Status LEDs

A red and a green status LED has been connected to free pins of the microcontroller. As the microcontroller can sink more current than it can source (18) (limited sourcing is not an issue with only two LEDs, but it is still good practice to avoid sourcing), the anodes of the LEDs are connected to VCC using 300R current limiting resistors. In this way the LEDs will light up when their pins are pulled to ground by the microcontroller.

JTAG interface

The JTAG interface is useful to program the unit as well as enabling real-time debugging. Four pins of the JTAG are necessary for the system to work:

- TCK (Test Clock)
- TMS (Test Mode Select)
- TDO (Test Data Out)
- TDI (Test Data In)

At the ATmega128 these are accessed via PORTF; PF4 to PF7, respectively. To simplify connection of the JTAG to the finished circuit board, these are connected to a standard 10-pole header connector, in the configuration shown at Figure 6-5. This configuration corresponds to the JTAG adaptor provided by Atmel, with their JTAG ice mk2, which will be used to program the microcontroller.

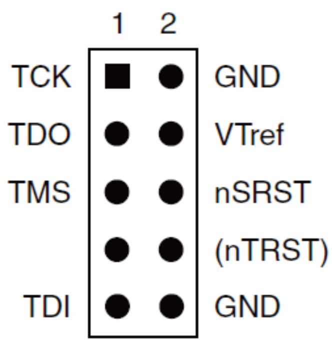

Figure 6-5: JTAG connector

Voltage regulator

A linear voltage regulator is included to be able to supply both the control electronics and the LED test display from the same power source. As described in section 5.1.1, the LEDs of the LED test display have a forward voltage of about 2.25 V at 25 mA. They are connected five in series to form a single display segment, so the maximum forward voltage per segment is 11.25 V. These are in turn connected between the positive voltage supply and the current sinking LED drivers. Because the drivers are very efficient, the system's supplied voltage can be as low as 12 V. But this voltage is still far too high for most microprocessors and integrated circuits. 5 V is the voltage required by the ATmega128, the same as with most other components. The voltage regulator in this application must provide the possibility of supplying the 5 V components from the 12 V (or higher) power supply.

The LM1086IS from National Semiconductor is a 1.5 A, 5 V low dropout regulator. Low dropout means that it can handle voltages only slightly higher than 5 V, while still being able to supply the correct 5 V. This feature is important in battery operated applications which have strict power budgets, but it is not a disadvantage in this mains powered application either. Because the voltage regulator "burns" the excess voltage, it can get very hot if the current passing through it gets too high. But as the microcontroller along with the rest of the components is very economic in terms of required power, this is not a problem. In fact, the biggest consumers of energy on the driver electronics board are the status LEDs.

Although the voltage regulator can handle input voltages as high as 35 V, the LED drivers cannot handle higher input voltages than 20 V. 20 V is therefore the highest allowed input voltage of the control electronics.

Decoupling capacitors

In digital circuits, there can often be problems related to noise from other components. Noise is often induced by devices switching fast on and off, such as the LED drivers, and might lead to unexpected errors or problems as a result of a slightly unstable supply voltage. By the use of a small capacitor between the supply voltage terminals of each digital circuit, this effect can be reduced as the high frequent noise is "short circuited" by the capacitor. 0.1uF decoupling capacitors have been used in this project.

6.3.2 Control electronics overview

Figure 6-6 illustrates the main components of the design. Not all components are included in the figure as they are not critical to the flow of information. The complete schematics can be seen in appendix B.1 and B.2.

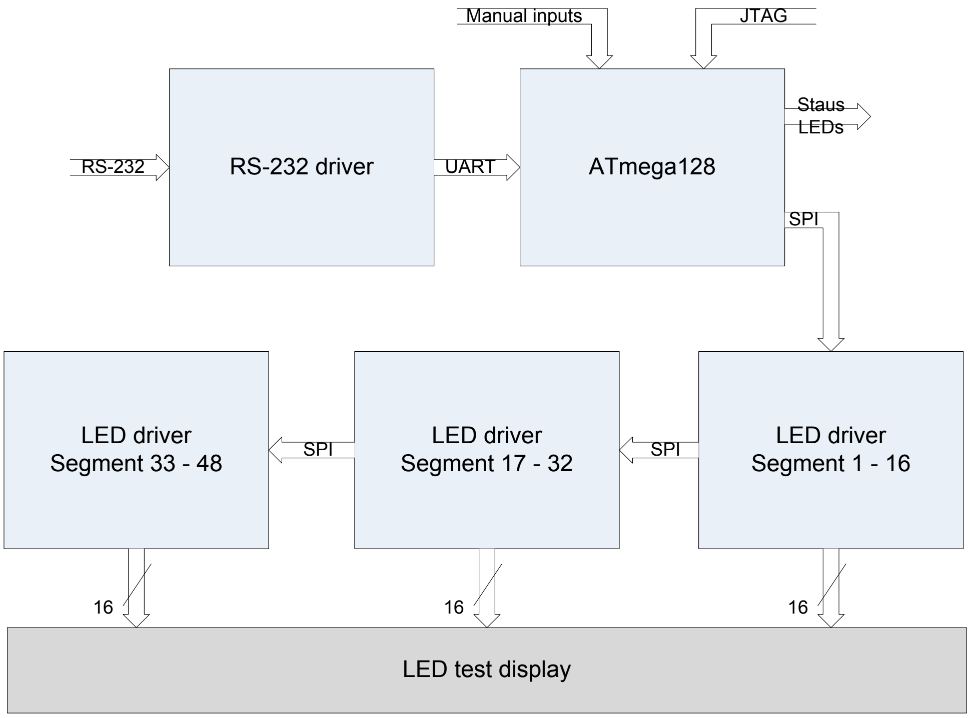

Figure 6-6: LED test display control unit block diagram

6.4 Driver electronics for the advanced display

These schematics are intended to control a display from Planar Embedded, and are complete with a high voltage output buffer. However, most components are re-used from the driver electronics for the LED test display, in this design. The main difference from the electronics for the LED test display is the increased number of outputs achieved by cascading more LED drivers. Because Planar Embedded failed to deliver displays, the PCB design is not done for these schematics.

6.4.1 Main components

Most of the components used in this design are already presented in section 6.3. Therefore, only one new component is necessary to introduce here.

High voltage output driver

As described in section 6.1, the use of photovoltaic relays is a good approach towards enabling safe control of the high voltage segments of the Planar Embedded display. Photovoltaic relays are a type of solid state relays. Solid state relays differ from ordinary relays by the fact that they have no mechanical parts; the switching is done by semiconductors, not by electromagnetic switches. Photovoltaic relays have an optical isolation between the control input and the output, as seen in Figure 6-7. This is very useful in applications such as this, were the voltage at the output side easily can damage the low voltage control electronics of the input side.

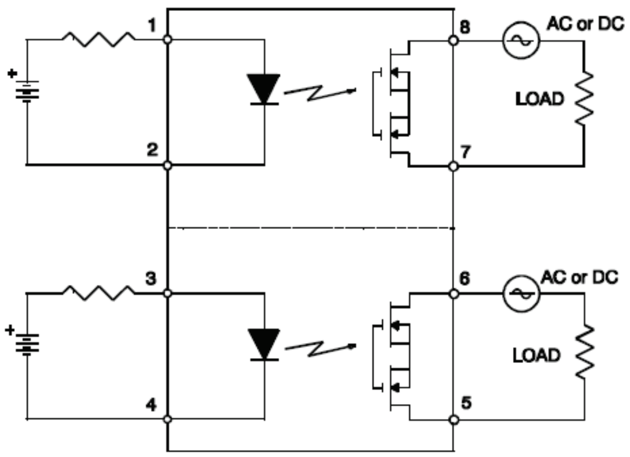

Figure 6-7: Connection diagram, PVT422 (19)

Figure 6-7 shows the connection diagram for the selected photovoltaic relay, the PVT422 from International Rectifier. As seen on the figure, the package has two separate inputs and outputs.

A complete output buffer module can be seen in Figure 6-8. This is module based, and can control 16 segments of a Planar Embedded electroluminescent display. Modules can be added to support a larger number of segments. The design done here has eight modules, to be able to control the 128 segments of the advanced display (Figure 4-3).

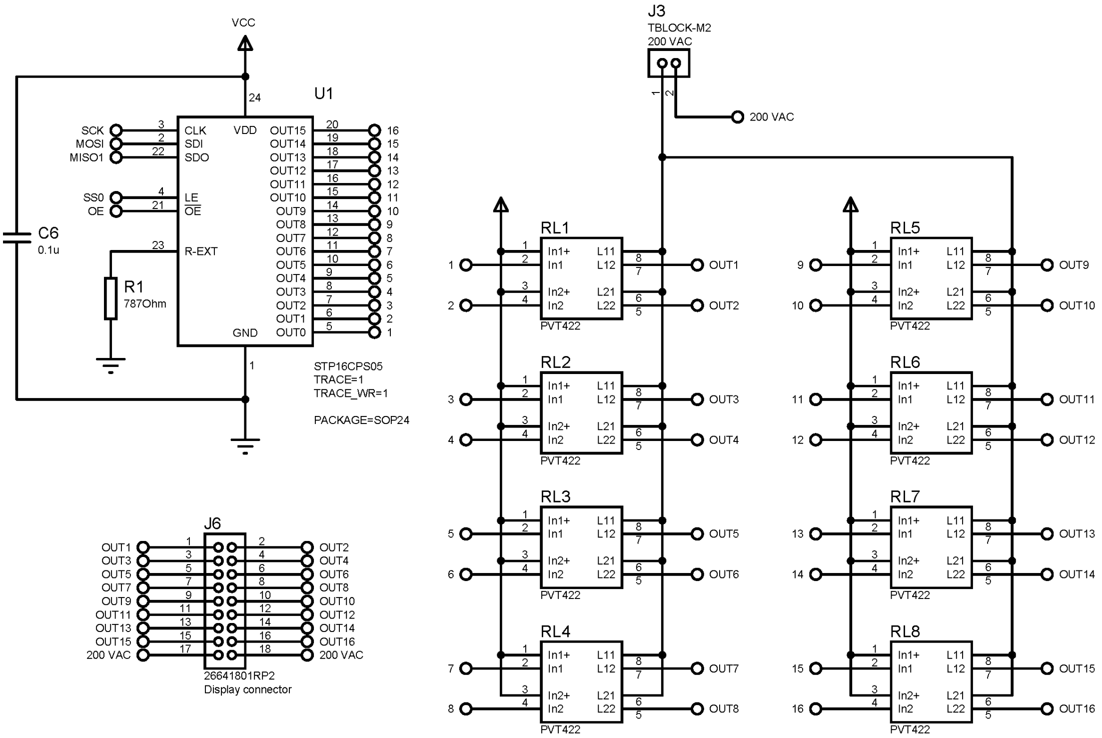

Figure 6-8: LED driver and output buffer, segments 1 – 16

6.4.2 Control electronics overview

As seen in Figure 6-9, the design is based on the same control structure as the electronics for the basic display. The difference is clear when looking at the increased number of outputs, and the added block of photovoltaic relays before connection is made to the display. The complete schematics can be seen in appendix B.1, B.3 and B.4.

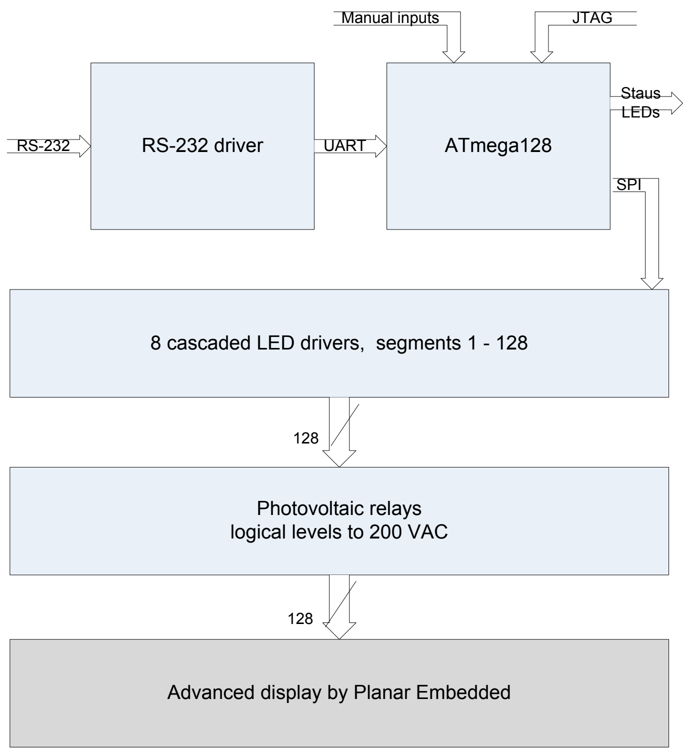

Figure 6-9: Block diagram, LED test display control unit

6.5 Prototype PCB

The PCB design for the basic display and its control electronics are done in Proteus ARES 7. Double layered circuit boards were chosen as more layers are impossible to make at the laboratories of Department of Engineering Cybernetics (ITK) at NTNU. As earlier mentioned, the driver electronics are connected to the LED test display using a standard connector. This is a 50 pole right angled header connector, male at the display and female at the driver electronics board.

Two different circuit board designs are made, whereas the first is only designed to be a connector board built into the LED test display. On one end, the cobber leads of the display segments are terminated. On the opposite end is the male version of the angled connector. The other circuit board is double layered and holds the driver electronics. A picture showing a close-up of the connectors can be seen in Figure 6-10.

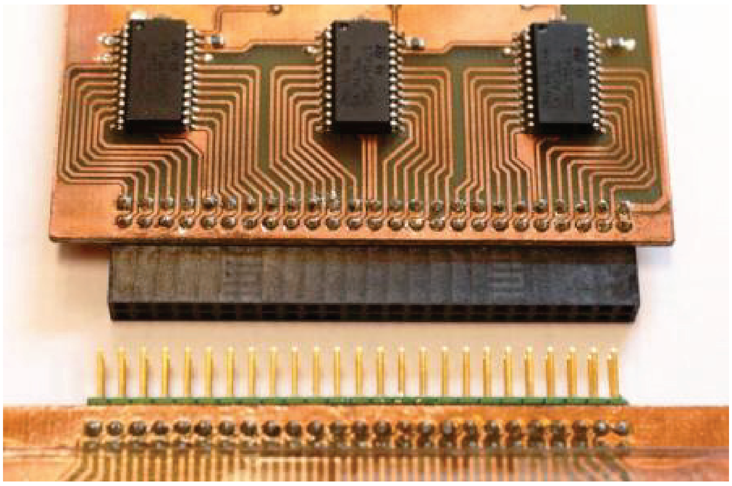

Figure 6-10: Connectors between driver electronics and display

A concern during the phase of designing was heat management. The total power of the display is nearly 11 W, as calculated in section 5.2. All this power is passed through and regulated by the three small LED driver circuits. How efficient they were was not stated in the datasheet. Therefore, it was decided to design the circuit board so that the three LED drivers are mounted with some space between them, to allow the heat to spread. The fact that the circuit board has a cobber ground plane on either side further helps on conducting heat away from the units. If the supply voltage is increased significantly, heat sinks should be considered to keep the LED drivers within their operating temperature.

Most of the components are surface mounted, but a few components, such as the connectors, are through-hole mounted. Because these designs are only prototypes, getting the printouts as small as possible and in a specific shape has not been top priority. The finished circuit board can be seen in Figure 6-11 at the next page.

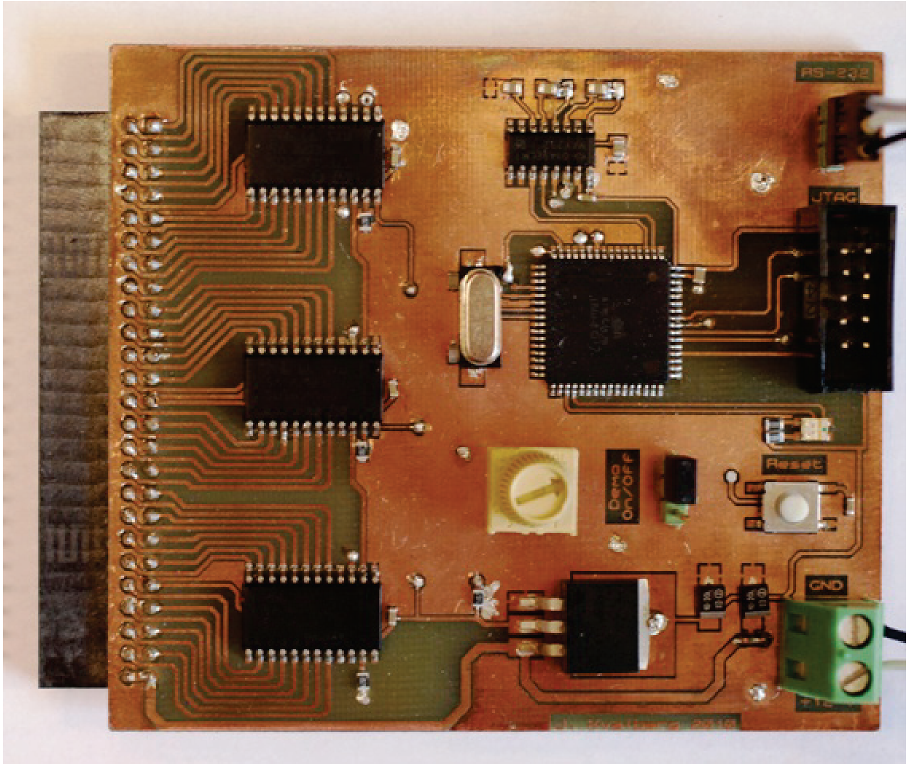

Figure 6-11: Driver electronics, component side

7 Software

The software is written in C code with the help of AVR Studio by Atmel. The driver electronics have a dedicated JTAG port intended for programming and real-time debugging. To program the ATmega128, a JTAG ICE mk2 has been used.

7.1 Software design

The program has a module based structure. Program functions are controlled and timed from a central repeating loop in a main-module. The modules are realized by separating the code in different files. Besides a control function, the main module does no computing. The control electronics has two different operation modes, based on the position of an on-board selector switch. AUTO mode enables the on-board potentiometer to adjust the display brightness, while the display's value is set by data received over RS-232. In DEMO mode, the potentiometer is used to manipulate the numerical value of the display directly, while the brightness value used in AUTO mode is stored and used in this mode as well. Figure 7-1 shows a state chart describing the main functions of the software.

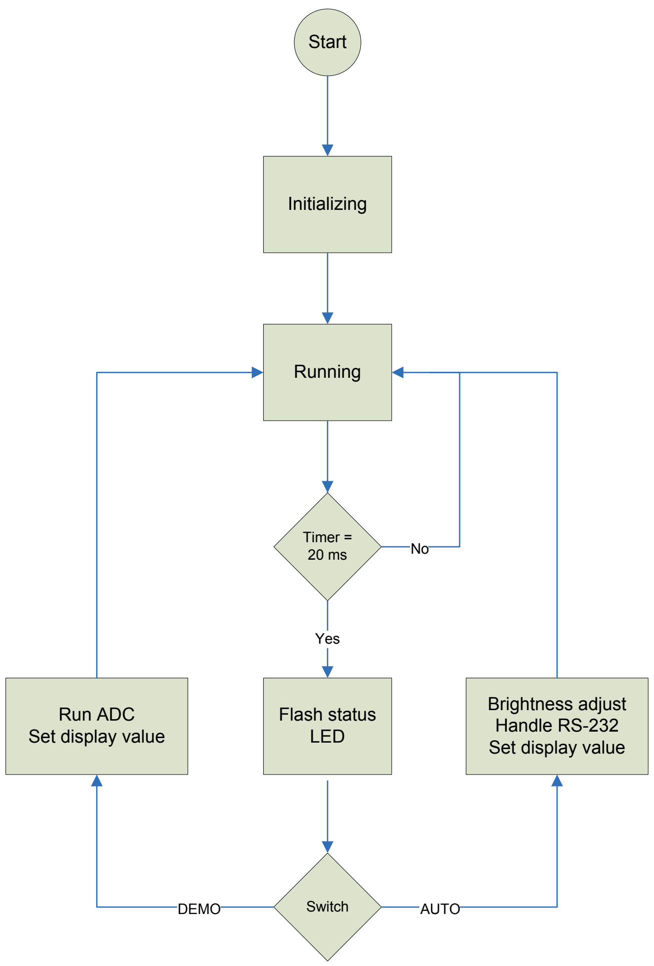

Figure 7-1: Software main functions state chart

The different program modules are presented in the following subsections.

7.2 Timing

Correct timing is an important aspect with real-time programming. Time is maintained by a timer interrupt. An 8 bit timer register is incremented as a function of the system clock, and is monitored by the microcontroller which interrupts when the register overflows. The process is then restarted, which gives a very accurate timing signal. This is done by hardware and is a very useful way to reduce the frequency of the system clock to a more practical level for controlling program functions. As the system clock of 4.9152 MHz increments the 256 position register, overflow will occur and generate a timer interrupt at a rate of

$$\frac{4.9152\ \text{MHz}}{256} = 19.2\ \text{kHz}$$

This frequency defines the *fast system timer*, which is used to generate a *main timer* as well as ensuring proper timing of the brightness control of the display. The main timer is made by code in a *timer module*. A variable is incremented by the fast timer and reset to zero every time it reaches a defined value. This value is chosen to 383, which gives a timing frequency of 50 Hz. Applications in the need of timing can get the current time by requesting the timer module. Most of the system components are timed by this timer.

7.3 SPI

SPI, Serial Peripheral Interface, is a serial bus working in full duplex mode. This makes it very fast, and because it is easy to implement in software, it is very much used. It supports only a single master, but multiple slaves accessed by separate slave select lines. The SPI bus specifies four logic signals (20):

- SCLK – Serial Clock (from master)
- MOSI – Master Output, Slave Input
- MISO – Master Input, Slave Output
- SS – Slave Select

SPI is used to control the LED drivers. As the LED drivers have no need to send data back to the master, the MISO line is not used at the master. However, because the LED drivers are connected in cascade, the MISO equivalent pin of the LED drivers is connected to the following driver's MOSI equivalent pin. Although the LED drivers are specified to have a SPI interface, they are connected using these slightly different signals:

- CLK – Serial Clock
- SDI – Serial Data In
- SDO – Serial Data Out
- LE – Latch Enable
- OE – Output Enable (active low)

The LE signal makes the internal latch circuit hold the data it passes from the input to the output. When OE is at high level, it switches off all the data on the output terminals. The LE signal is programmed to give a high pulse after the data is sent, according to the timing diagram of Figure 7-2. The OE signal is managed by the *brightness control module* of the software. This is described in section 7.5.

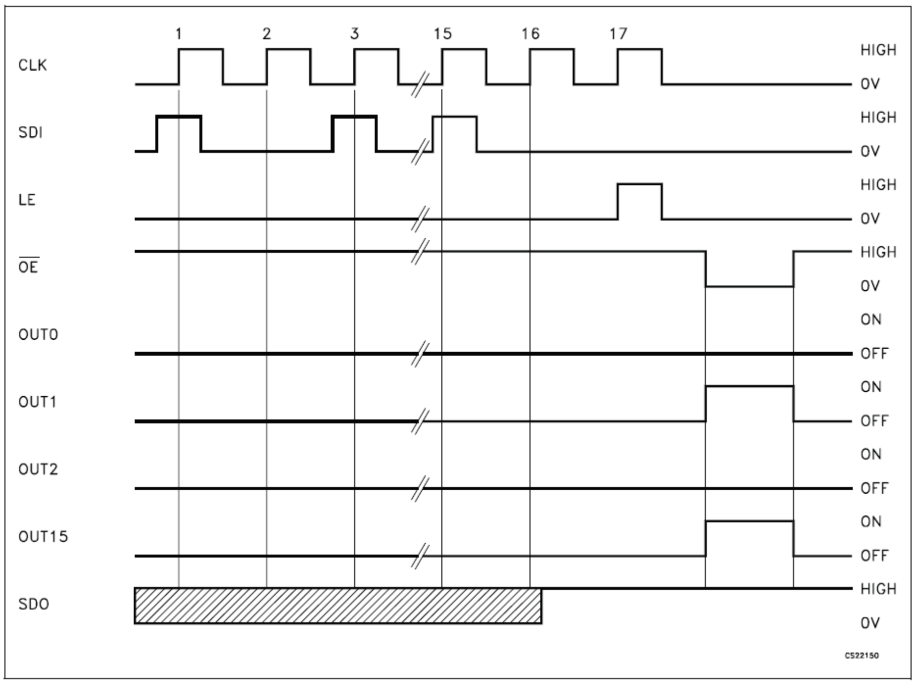

Figure 7-2: STP16CPS05 LED driver timing diagram(16)

7.4 Display driver

The main task of the *display driver module* is to convert integers it receives so that the display will give the right representation of the number.

Each LED driver chip has 16 outputs. As a standard numerical indicator has eight segments including comma, the segments are connected so that each bit control a numerical segment indicator. The microcontroller accesses the drivers via SPI, and each chip has latching capacity of two bytes, equivalent to 16 outputs. SPI is transmitting one byte at a time. As the LED drivers are connected in cascade, only the first chip receives the byte in the first cycle. However, they all pass on the first latched byte they have, but at startup, these bytes are all zero. After six bytes are sent, all the LED drivers have new data in their latches. The last chip in the cascade has the first byte sent in its last latching position, and the first chip has the last byte in its first latching position. These six bytes are updated and sent from the microcontroller every 20 ms, timed by the 50 Hz main timer. Between these updates, the drivers hold the old value at their outputs.

The main computing part of the module is the converting process from integers to meaningful output on the display. When the display is updated via RS-232, the received data comes in a string of chars. This introduces another element to the converting process, but this is taken care of by the *RS-232 interface module*. Although it is easy to think that received chars from the RS-232 receiver should be possible to send directly to the LED drivers (a char is after all a byte) the following example will show why the converting is critical to obtain the correct result:

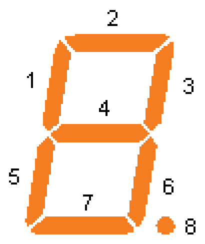

Figure 7-3: Indicator segments numbering

The display segments are numbered as shown in Figure 7-3. To get all segments to light up, all the bits in the byte controlling this indicator must be “1”, so that the transmitted byte looks like “0b11111111”. The indicator will then show the value “8.”, although the decimal value of the byte sent is 255.

In addition to the numerical value of the display, it also has an alarm sign. The alarm sign is programmed to flash if an “A” instead of the default “a” is added to the string received via RS-232. The alarm sign can also be programmed to flash by other program functions by setting an alarm value accessed in the display driver module.

Figure 7-4 shows a state chart illustrating the operation of the display driver module.

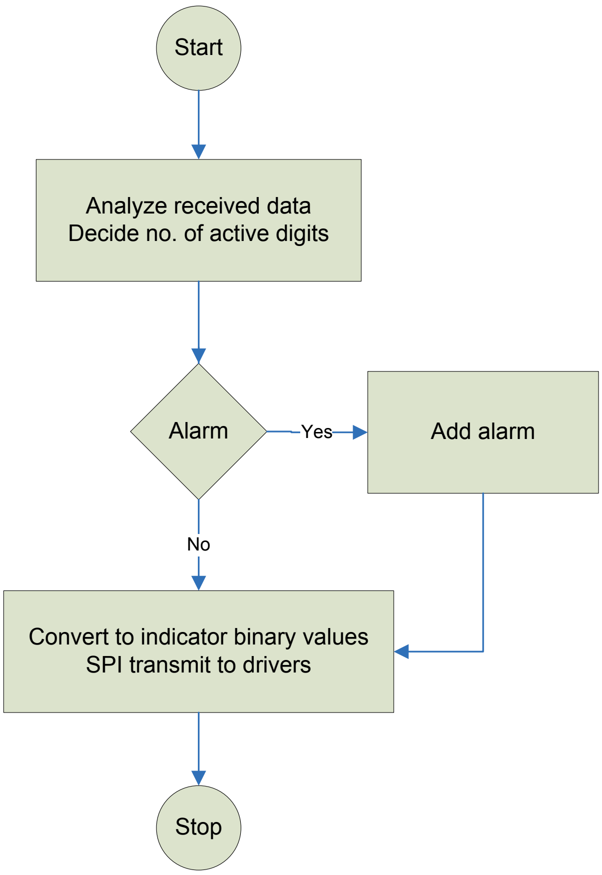

Figure 7-4: Display driver module state chart

7.5 Brightness control

To compensate for different lighting conditions, brightness control of the display is essential. In a real application an operator would be blinded at night by the display brightness needed in bright daylight. Likewise, an operator would have had great difficulties in reading the display in daylight if the brightness was set to be at a satisfactory level at night.

The LED drivers have constant current regulators at all of their outputs. The output current is set by an external resistor, chosen in this project to be 25 mA, as this is the maximum allowed continuous current through the LEDs. The photovoltaic relays of the high voltage output buffer for a display by Planar Embedded can also handle 25 mA.

By varying the resistance of the external resistor, the output current can be adjusted from 5 – 100 mA. This gives a possibility of brightness control. External digital resistors could have been used to be able to control the brightness by varying the resistor by software. However, a fixed resistor is chosen. One of the reasons for this is that the lower limit of 5 mA of the current regulators will still mean quite bright LEDs. As the display is an arrangement of almost 200 LEDs, the combined light output at 5 mA would be too high as a lowest setting. The other reason why fixed resistors are chosen is that introducing digital resistor circuitry is more complex than controlling the brightness in the way described below.

The output of the LED drivers can be turned ON or OFF by accessing the *output enable* (OE) pin of the chip. A brightness value, ranging from 0 – 100, is set through a function in the *LED driver module*. This value represents roughly the actual brightness of the display from 0 – 100 %. Based on this brightness, a function in the *LED driver module* is turning ON and OFF the OE of the LED drivers. In other words; if the brightness value is 40, the function will ensure that OE will be ON for 40 % of a given time. The given time is a function of the fast timer, and needs to be short and quickly repeating to avoid visible flicker of the display. In practice, this way of controlling the brightness is exactly the same as *pulse width modulation*, or PWM.

7.6 RS-232 interface

The RS-232 interface is intended for controlling the display from a remote computer or control system. In addition, the RS-232 interface is very useful during the process of developing software, because values can be printed in real time directly to a terminal at the programming computer.

When data is received by the RS-232 transceiver and passed on to the ATmega128, an interrupt is generated. This initializes a piece of code that stores the data in a buffer for later use. As the data received is a series of chars, the software is analyzing the received data, and converts numerical values to integers. Because the test display has only five digits, the format of the received string must be one to five digits, separated by an optional comma, to be sure the output is correct. To generate an alarm, an "A" is added to the string. Format examples: "123.45A", "347", "0.3" etc.

This module also defines the format of the data exchange over RS-232:

- Baud rate 19200
- Eight data bits
- Even parity
- Two stop bits
- None handshaking

7.7 ADC

To be able to manipulate different parameters of the display manually, the driver electronics have a potentiometer and a selection switch as seen in section 6.3. Adjusting the potentiometer regulates the voltage it inputs to the ATmega128. For this digital device to be able to understand this analogue value, it needs to be converted to a digital counterpart.

This is done by the internal ADC of the ATmega128. The ADC is configured and initialized by setting certain register bits. These include setting the speed of the ADC, voltage reference for the analogue conversion and which input pin of the microcontroller to convert. The very conversion process is done by hardware, and the result is obtained by reading the ATmega128's ADC result register.

When the driver electronics is in AUTO-mode, the value from the ADC is used to adjust the brightness of the display. In DEMO-mode, it is used to set the numeric value of the screen, from 0 to 2000.

7.8 Computer software

A basic demo program has been made in order to achieve a better HMI between the user and the display than what is provided by a standard RS-232 terminal. The demo program is made in Citect SCADA (Supervisory Control And Data Acquisition), which is a product offering a complete SCADA/HMI solution, and is widely used worldwide in many different applications. Programming can be done both graphically and by writing code. It was chosen due to previous experience with the program.

The Citect SCADA application which was made to control the display has to user inputs in the form of two graphically adjustable meters. One for the numerical value of the display, called *Indicator value*. The other is called *Alarm limit*, and adjusts a monitored threshold. If this is exceeded, the program will trigger an alarm. In a real application, an example of an alarm limit can be the total allowed load of a crane, and might be changing dynamically based on type of load, changed radius of the crane hook etc.

Figure 7-5 shows a screen printout, with the alarm triggered. Behind the graphics seen on the figure is a piece of code reading the value of the two meters. This is analyzed, before the result is written to a COM-port and sent to the control electronics of the display every 800 ms. The code is written in Cicode, a programming language developed by Citect. The code can be found on the attached CD.

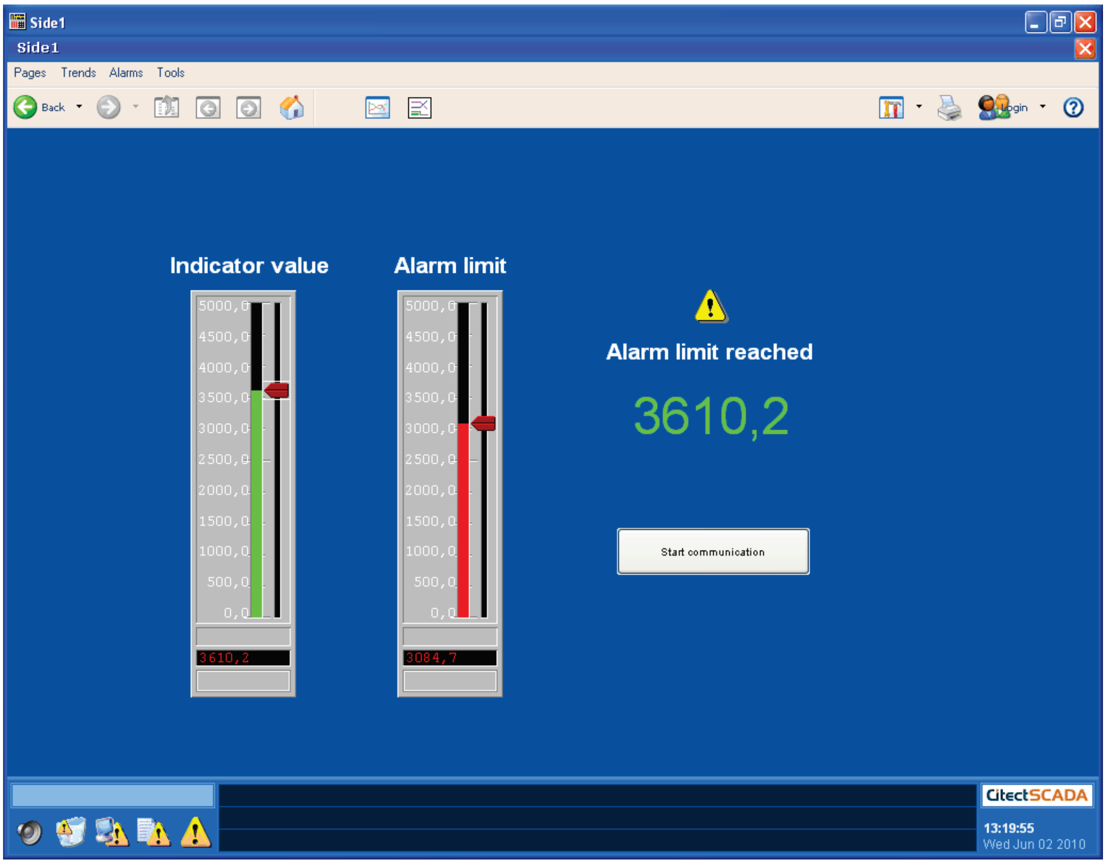

Figure 7-5: Screen printout, CitectSCADA demo program

8 Prototype testing and evaluation

The prototype of this thesis is divided into two parts; the control electronics and the LED test display. As previously described, the driver electronics was initially intended to be used with a custom made transparent display by Planar Embedded. Such a display can still be delivered in the future, and can by the addition of a high voltage output buffer be controlled by the electronics designed here.

As the LED test display is not as transparent or easily readable as a professional display, it will not do the job towards convincing NOV costumers into buying an expensive head-up display system. However, the display proves the control electronics work and that there is great a potential to the technique. This is precisely the job it was made to do.

8.1 Control electronics

The control electronics has worked as intended. No major problems have occurred in the process of designing and building. The fact that it was chosen to design electronics driving each display segment separately and not multiplexed, resulted in a robust design. If a multiplexed solution had been chosen, the LEDs of the display segments must have handled a higher peak current in order to keep the brightness on the same level as direct driven. For example, if two LEDs are to be controlled by multiplexing, each LED can only be ON for 50 % of the time. This means the current through each LED must be twice the current needed when operated continuously (more thoroughly discussed in section 0). If there occurs a problem and the control unit crashes, even for a little time, LEDs might be destroyed due to an extended period of ON-time. The LED drivers, on the other hand, have a hardware safety in terms of an external resistor which limits the output current and prevents overload of the display segments under any circumstances.

Heat management of the LED drivers was a concern during the phase of designing. However, even though the maximum power of the display is nearly 11 W, the three driver circuits barely get hot. If the supply voltage is increased, the necessary dissipation of heat from the drivers will increase as a higher voltage difference must be “burned off”, and a heat sink might be considered.

8.2 LED test display

As mentioned in chapter 5, the LED test display is not to replace a professional display. It is only a prototype, meant for inspiration of what a transparent display in a HUD application can look like. In addition, it also serves to prove the control electronics made as the major part of this Master thesis actually works as intended.

The surface of the display did not reach the high quality finish expected. Two test castings were made before doing the final display, and all of them failed on achieving the specified finish. Whether this was because of a bad batch of epoxy or because of slightly inaccurate mixing ratios of resin and curing agent is difficult to know. To improve this, the display was first sanded down before several layers of clearcoat were sprayed on the surface of the epoxy to get a harder surface. All of this mechanical work led to a slightly uneven surface, which unfortunately affects the clarity of the display when looking at distant objects. However, the display still works well as a desktop model to show the principle of head-up display systems employing a transparent screen. An example can be seen below in Figure 8-1. If there was more time, it would have been interesting to make a new display, hopefully getting the glass-like finish the epoxy was supposed to have.

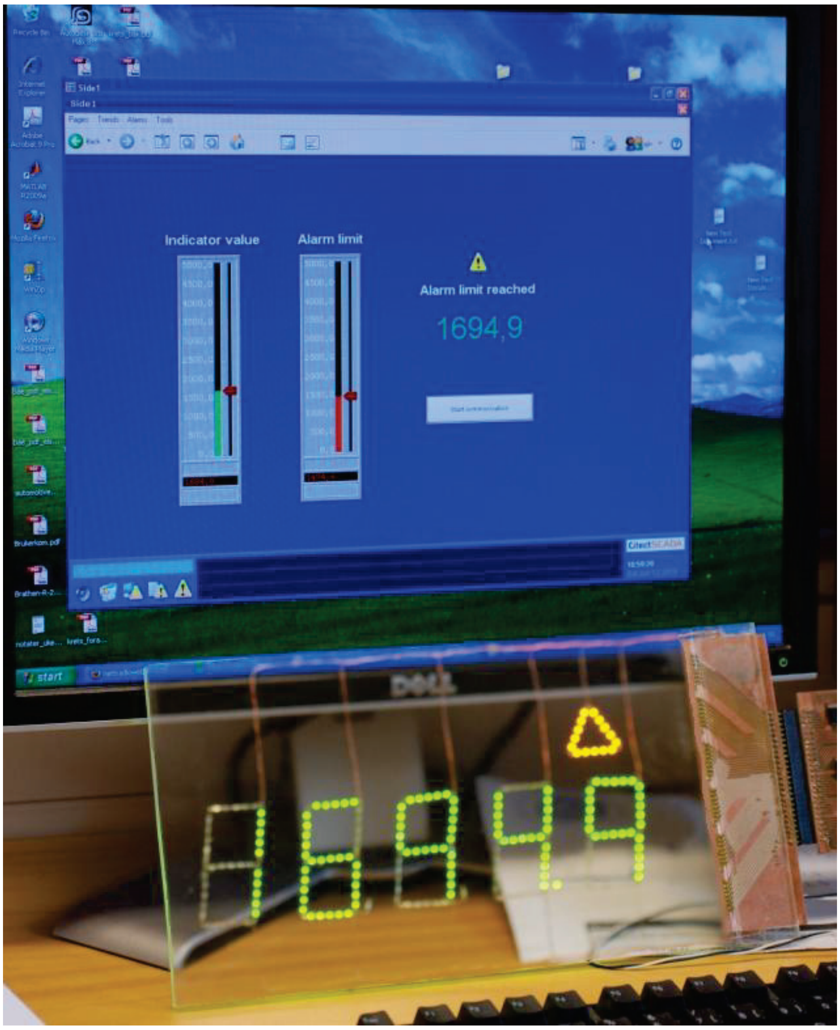

Figure 8-1: LED test display connected to the PC and synchronized with the Citect application running in the background. As the alarm limit is exceeded, an alarm sign is flashing at both the PC-screen and the test display.

The brightness of the display was very satisfactory in practice. As mentioned in chapter 5, the combined power consumption of the LEDs is about 11 watts, which means quite a lot of light when speaking of LEDs. Combined with the effective brightness adjust possibilities of the control electronics, the display can be read under any lighting conditions. Even though the display is very bright at maximum brightness, it is not uncomfortable to watch. Probably, this is because the light is spread evenly from the LED emitters. Originally, the LEDs had an effective viewing angle of about 25 degrees, which gave a more focused light. In a display application, a viewing angle of 25 degrees is not very much. An LCD screen, in comparison, has a viewing angle of about 170 degrees. When the specific LEDs were bought, a part of the plan was that the epoxy of the embedding cast would cancel out the focusing effect of the LED body's epoxy lens, and by that increase the viewing angle significantly. This turned out to be correct in practice, resulting in a viewing angle of nearly 180 degrees.

8.3 The complete HUD prototype

After testing the LED test display and control electronics as a HUD module, there is no doubt an introduction of transparent screens in operator cabins may lead to an improved sense of control and better access to important variables, as these can be presented more conveniently than with a standard display. Even though the test display is not as transparent as hoped for, it is still possible to keep an eye on the background when looking through the display.

Because the display emits light by itself, it can very effectively catch the viewer's attention. For example, if an alarm occurs, the alarm sign of the display can flash with maximum brightness to be sure the viewer is alerted as fast as possible.

9 Further work

Although not written in the problem description, one of the goals of this project was to implement a head-up display pilot system into an NOV operator cabin. This however, was effectively stopped by the undelivered displays from Planar Embedded. This means a professional display still needs to be made. The electronics made in this Master thesis can easily be expanded to drive any number of outputs to support other displays than presented in this report. The PCBs can be made in modules, so that more outputs can be added by just connecting another output card and doing a software update.

When a driver electronics prototype is finished and its functionality is proven, effort should be made to reduce the printout size of the driver electronics, to be able to hide it as much as possible. In the case of electroluminescent displays which cannot support multiplexing, this is especially important. This is because such displays require a separate line to all display segments. By having professionals make the PCBs, the printout can be made a lot smaller even with the same components used today. Multilayered PCBs can furthermore reduce the printout size, because routing can be done internally and avoid occupying space at the component sides.

The LED test display made as a consequence of the undelivered electroluminescent display by Planar Embedded gives an idea of what might be possible to achieve with a professional display. As Planar Embedded is the only supplier of this kind of displays, it is smart to take another turn in investigating new technologies and possible new suppliers. Different head-up display solutions will very likely appear in many different applications in near future. Therefore, the concept should not be thrown away only because a very promising product could not be delivered and time was wasted as a result of an unsuccessful delivery.

On the way towards completing a prototype custom made for an NOV operator cabin, the driver electronics also has to be upgraded to support and provide an interface for the NOV control system, which is often Profibus DP (8).

10 Conclusion

Even though the project did not go completely as planned as a result of the unexpected cancellation of a professional display, the goals of the project are fulfilled. An LED test display was made to be able to test the driver electronics as well as giving an impression of the capabilities of a transparent screen. Driver electronics able to control the original display by Planar Embedded as well as the test display were made. This enables remote control of the display by RS-232 or via the on-board manual inputs.

After testing the LED test display, it seems very likely that an introduction of transparent screens in operator cabins may lead to an improved sense of control due to easier monitoring of important variables. With a transparent display, these can be presented more conveniently than with a standard display.

11 Bibliography

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Appendix

A Bill of materials for the prototype PCB

7 Resistors

Quantity	References	Value	Order Code
3	R1-R3	787Ohm	Digikey P787LTR-ND
2	R4, R5	49.9K	Digikey P49.9KLTR-ND
2	R6, R7	300	Digikey 311-300LCT-ND

14 Capacitors

Quantity	References	Value	Order Code
4	C1-C4	1.0u	Digikey 399-1255-1-ND
6	C5-C9, C14	0.1u	Digikey 399-3521-2-ND
2	C10, C11	10u	Digikey 495-2260-2-ND
2	C12, C13	22pF	Digikey 445-1778-2-ND

6 Integrated Circuits

Quantity	References	Value	Order Code
3	U1, U3, U4	STP16CPS05	
1	U2	ATMEGA128	
1	U5	MAX232	
1	U6	LM1086IS	

1 Diodes

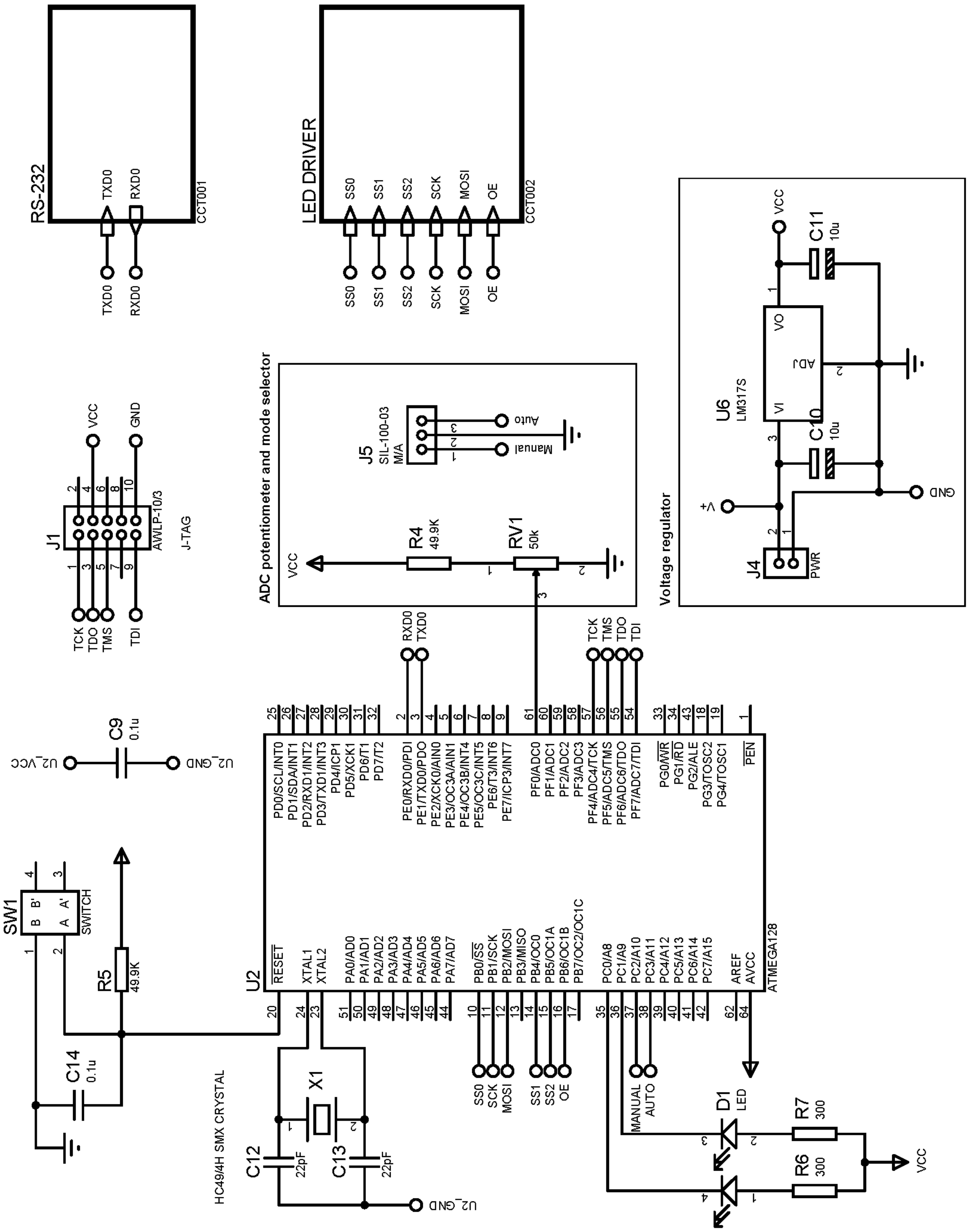
Quantity	References	Value	Order Code
1	D1	LED	KPB-3025ESGC-F01

8 Miscellaneous

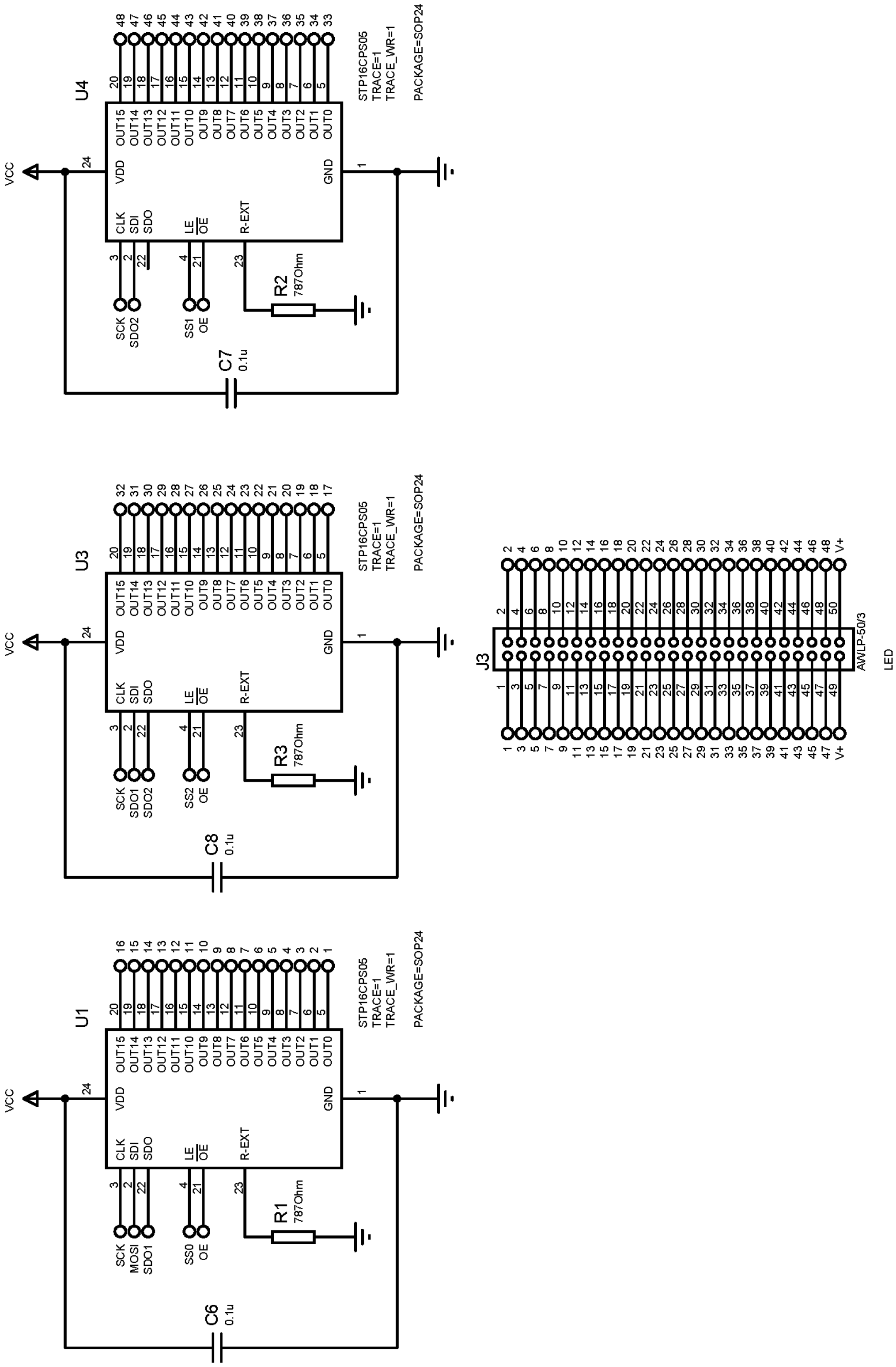
Quantity	References	Value	Order Code
1	J1	AWLP-10/3	Digikey HDM10H-ND
2	J2, J5	SIL-100-03	
1	J3	AWLP-50/3	Digikey HDM50H-ND
1	J4	TBLOCK-M2	
1	RV1	50k	M63M503KB30T607
1	SW1	SWITCH	
1	X1	HC49/4H SMX CRYSTAL	

B Schematics

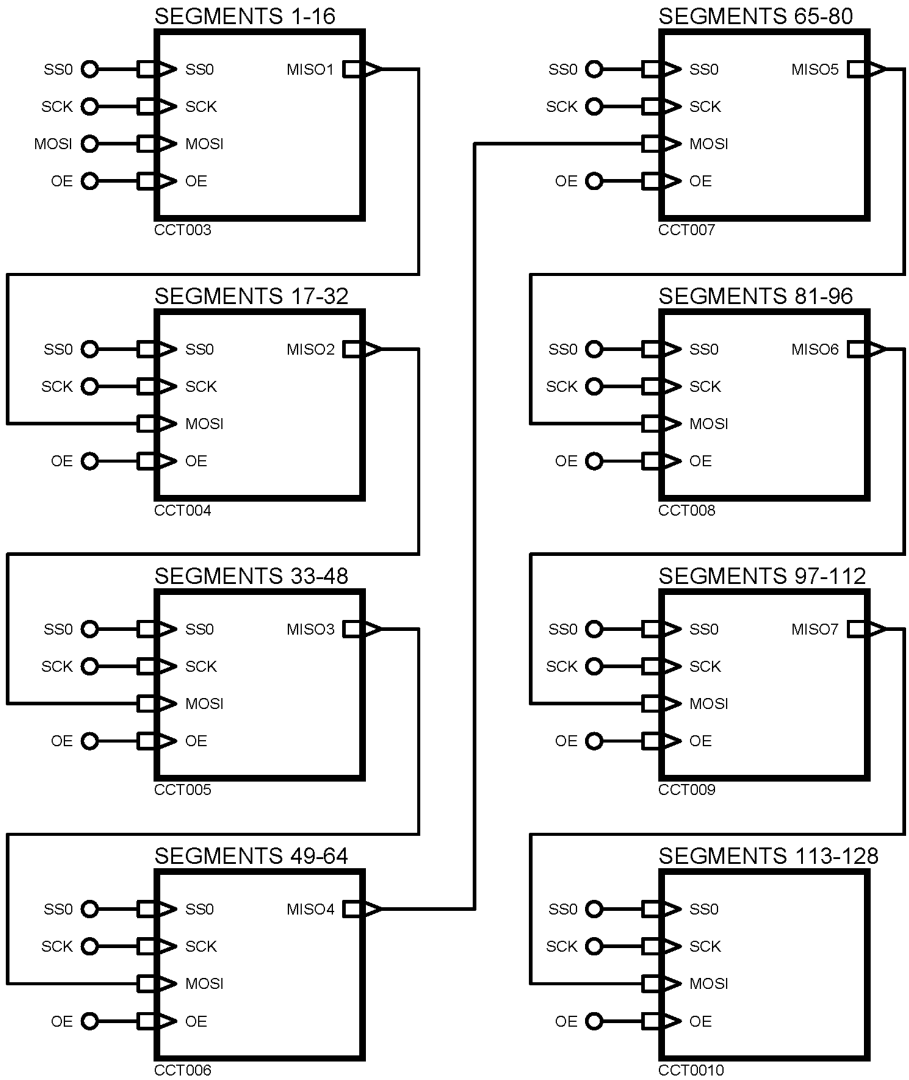
B.1 Driver electronics for both electronics designs



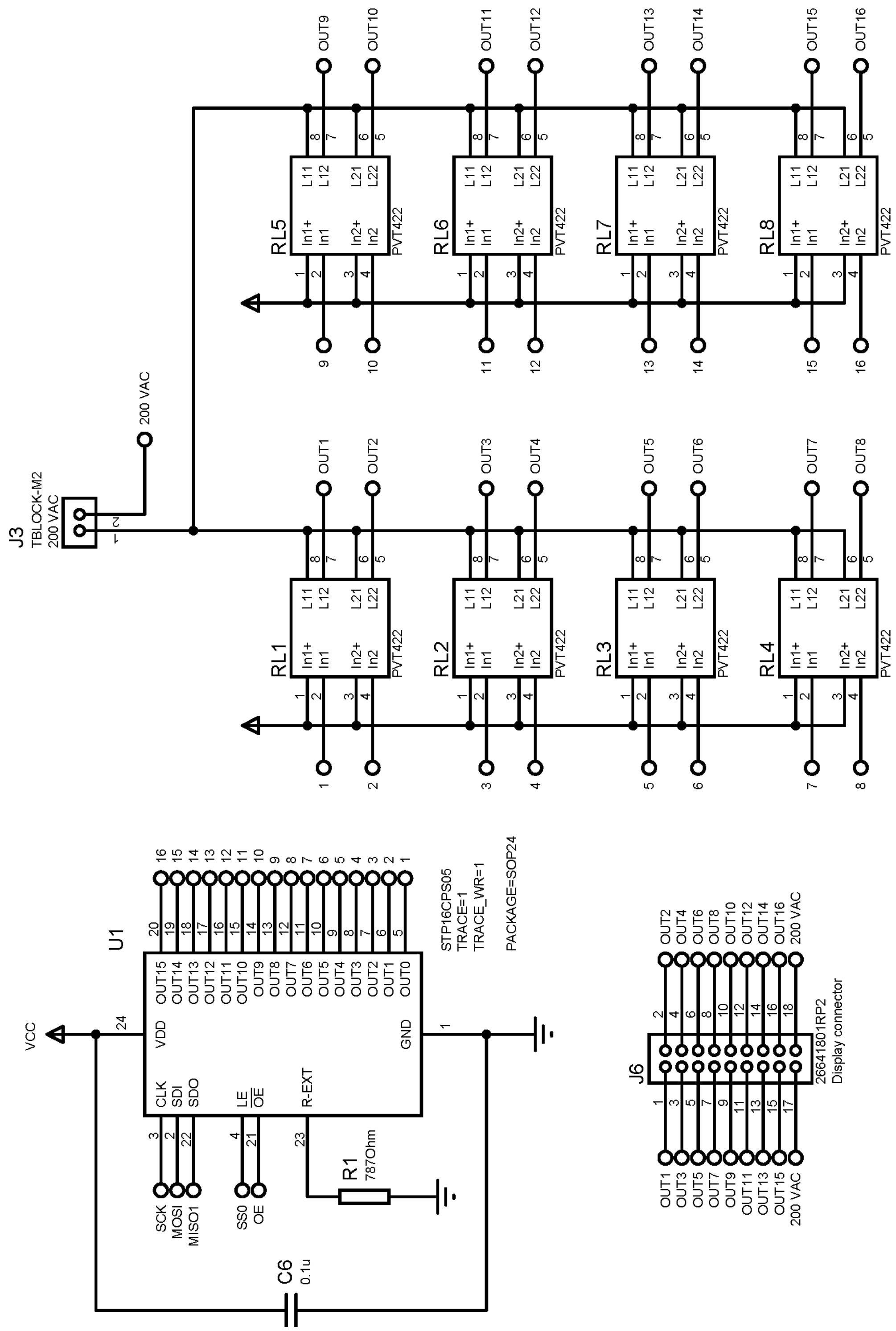
B.2 Contents of subcircuit LED DRIVER for the LED test display



B.3 Contents of subcircuit LED driver for the advanced display



B.4 Contents of the module based SEGMENTS subcircuits



C Contents of attached CD

- Electronics design
- Software for the control electronics
- Citect SCADA application for controlling of the display from a PC
- Datasheets
- Pictures
- .pdf and .docx versions of this report and the preceding report