# Analysis and design of a new control system for aerodrome azimuthal guidance
# – The SAGA

# Analysis and design of a new control system for aerodrome azimuthal guidance – The SAGA

Joakim Arnsby, Mårten Kjellsson

LUNDS UNIVERSITET

Department of Automatic Control

Department of Automatic Control
Lund University
Box 118
SE-221 00 LUND
Sweden

ISSN 0280–5316
ISRN LUTFD2/TFRT--5920--SE


Printed in Sweden by Media-Tryck.
Lund 2013

# Abstract


This master thesis work consists of the development of new hardware and software for the control box of an azimuthal guidance system used by aircrafts during the approach to the runway. The thesis work was done at Safegate International AB as a project running along the usual development projects.

When designing electronics to be used on an airfield there are a lot of regulations and standards that need to be taken into consideration. To ensure the project turned out to match the demands, some project management documents where drafted, both documents that specified requirements and documents that specified different tests to ensure the prototype did what it was supposed to.

As the project finalized, two prototypes of control boxes were installed and working on one azimuthal guidance system. These prototypes included full documentation and changes to existing manuals to be able to make the new control boxes part of the Safegate experience.

# Acknowledgements

We would like to thank our supervisors, Andreas Wirandi and Mattias Hallberg at Safegate and Anders Robertsson at LTH, for all their help with the project management and expertise in their different fields. We would also like to thank Ola Håkansson, Jörgen Persson and Peter Körner for valuable comments on the ongoing work as well as bringing new ideas to our minds.

# Contents

# Abbreviations

| | |
|---|---|
| FAA | Federal Aviation Administration |
| ICAO | International Civil Aviation Organization |
| IEC | International Electrotechnical Commission |
| ILS | Instrument Landing System |
| IPC | Association Connecting Electronics Industries |
| MCU | Microcontroller Unit |
| PAPI | Precision Approach Path Indicator |
| PCB | Printed Circuit Board |
| PSU | Power Supply Unit |
| RMS | Remote Management System |
| SAGA | System of Azimuthal Guidance for Approach |
| STAC | Service Technique de l'Aviation Civile |
| TLOF | Touchdown- and Liftoff-area |

# 1

# Introduction

This master thesis work is a project within the corporation Safegate International AB and consists of product development of a control box for one of their existing products. Everything from planning to a finished prototype is included with both software and hardware as well as documentation.

The control box is to be used in the product called SAGA (System of Azimuthal Guidance for Approach), which in short is used for guiding aircrafts to the correct approach axis while approaching the runway or the helipad [Safegate International, 2013].

The prototype developed during the thesis work should be compliant with applicable regulations and standards and should lower the production cost of the control box by at least 50%. It should also follow the specifications of the old SAGA system and, where possible, be upgraded as much as possible while still maintaining backward compatibility.

# 2

# Background

Safegate International AB is a company in the airfield business which currently holds a noticeable market share in airfield equipment, both docking systems and lighting. The company's product portfolio includes everything from guiding an aircraft during landing to making sure the aircraft can safely drive to and dock at the correct airport terminal.

The SAGA system, which this thesis work is about, was introduced to the market in 1991 and has not been updated much since then. As this was quite a long time ago the electronics are outdated, expensive and some parts will according to suppliers not be available much longer.

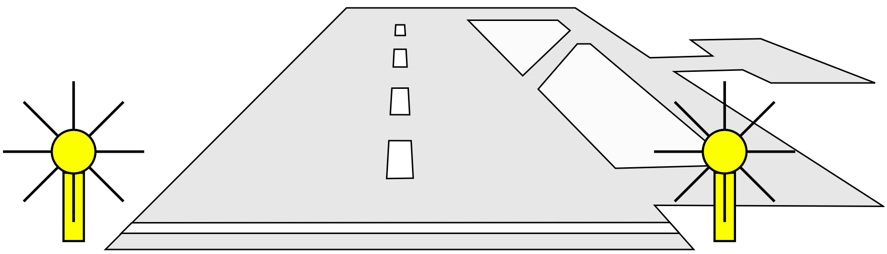

**Figure 2.1** SAGA placement besides runway

## 2.1 Product description

SAGA is a product that provides visual guidance of azimuthal offset during approach in form of two flashing lights, placement as seen in Figure 2.1. The lights are seen simultaneously while approaching inside a $\pm 0.45^\circ$ angle of the approach axis. If outside this angle but inside a $\pm 15^\circ$ angle of the axis, the closest flash is seen before the other one to guide the pilot to the correct approach. When flying outside the $\pm 15^\circ$ angular sector the flashes are no longer visible. The specifications of the system are taken from the product sheet of the SAGA [Safegate International, 2013].

## 2.2 Current market for SAGA

The SAGA is a small and neat guidance system to be used either as a backup for larger ILS (Instrument Landing System), or more commonly for use on small airfields where there are no control towers or larger lighting systems. It has been installed in a lot of different places spread over many different continents, from heliports on top of hospitals to airfields with tricky approaches in small mountain villages.

# 3

# Specification of thesis work

The main object of this master thesis is to substitute the previously, almost unknown, electronics in the SAGA units with a new cheaper and better documented electronics design. This should be done by designing a new hardware and software as well as looking for possible of-the-shelf products and comparing them to each other.

As a final task, to make the new design more likely to be used in production, the project shall include an assessment of risks regarding lifetime of used components.

The demands from Safegate on the master thesis work were formulated as follows:

- Review the existing design of the SAGA units and to collect knowledge how the electronics and software works. What components drive the cost today?
- Collect the requirements for the fitting regarding standards, market demand, bench marketing etc.
- Benchmark and analysis of existing "of-the-shelf" control and regulation system. Could existing Safegate components be used (from AFL (Airfield Lighting) or DGS (Docking Guiding System) products etc)
- Suggest and evaluate different solutions. Electrical and software design phase (goal: reduce the cost by 50% of the electronics)
- Risk analysis of sourcing of the components. Consider future availability.
- Create documentation for production such as BOM and CAD files.
- Prototyping
- Test and verifying according to the defined design parameters.

## 3.1 Demarcation

The project does not include any change to the mechanical structure and, as the project's result shall be a prototype, final preparations for production are excluded as well.

## 3.2 Development Framework

As the master thesis work is running in parallel with Safegate's ordinary projects it was decided that it should follow the same development framework as other projects. The framework used by Safegate could be seen as an extended version of the V-Model [Waterfall Model, 2013], as shown in Figure 3.1.

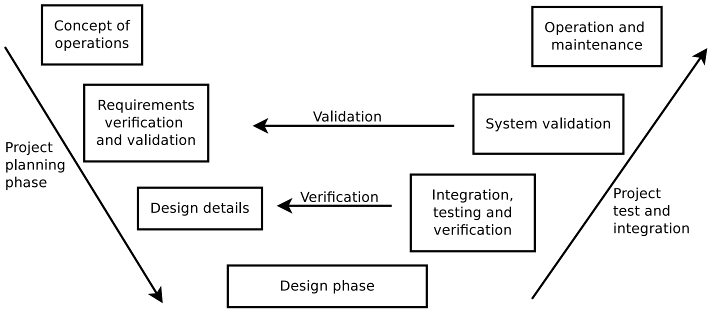


**Figure 3.1** The development framework simplified as the V-Model

To ensure a developed product actually fulfils the demands of the intended product, a requirement document will be written. The requirement document will then be used to write a product verification and a product validation. These two latter documents intend to verify that the product actually fulfils the requirements, and to validate that the finished product fulfils the initial demands.

During the development the written documents will be consulted to ensure the product turns out to perform as it was intended to.

# 4

# Planning phase

As the few specifications that exist for the SAGA system does not say much about how the product work, an extensive reverse engineering was performed to gather as much knowledge as possible from the old products. During the reverse engineering a lot of tests were made on the old product to confirm it followed the specifications that exist and to understand what parts are important.

When the reverse engineering was done, the planning of how the new control system should work began. During the planning phase a lot of different design possibilities were tested to see which components and which designs should be used and which should not.

## 4.1 Regulations

In general when it comes to airfield equipment it is, as in so many other fields (see Figure 4.1), regulated through a great number of different standards used by an equally great number of countries. The main one used by European countries is IEC (International Electrotechnical Commission) which is based on regulations by ICAO (International Civil Aviation Organization), a world spanning organization. In the United States they use the FAA (Federal Aviation Administration), also based on ICAO, and France have their own STAC (Service Technique de l'Aviation Civile) to set their regulations.

Even though there are a lot of different organisations with specifications and demands on a lot of different types of lighting, the SAGA does not have any dedicated demands. As Safegate is the only company that can provide a SAGA these organisations have not yet included it in their regulations, even though the product has been on the market for some time.

The standards and regulations the SAGA system should be compliant with were summarised and the SAGA Product Requirements [Arnsby and Kjellsson, 2013b] was drafted.

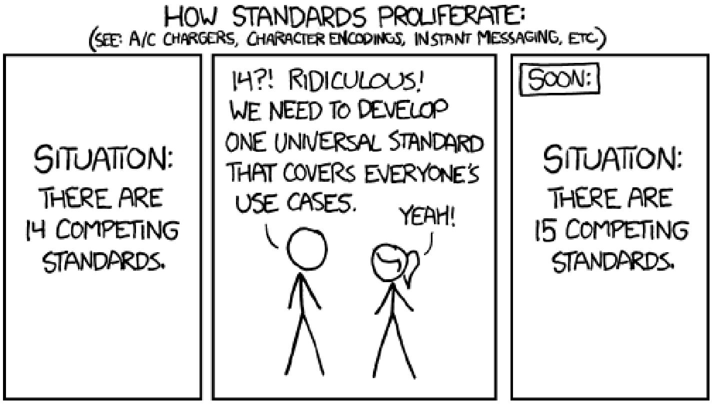


**Figure 4.1** Reason for number of standards [Randall Munroe, 2011]

### PCB Regulations

As well as the aerodrome associations regulations the design have to comply with standards regarding electronics design. When the work on this thesis started Safegate had no general directions on which standards to follow or what demands should be put on PCB design. Before any PCB schematic could be designed the relevant standards have to be specified. Most electronics design companies comply with the IPC and they are, according to a quick market research, the main electronics design standards providers.

The IPC standards that were considered useful in this project are the following:

- IPC-2152 -Standard for Determining Current Carrying Capacity in Printed Board Design:
  This is important since the current running through the PCB will be in the area of 10A.
- IPC-2221b -Generic Standard on Printed Board Design:
  To ensure a good PCB design this over all standard is good to comply with.
- IPC-7351b -Generic Requirements for Surface Mount Design and Land Pattern Standard:
  To make the PCB producible it is important to comply with land pattern standards.
- IPC-D-279 -Design Guidelines for Reliable Surface Mount Technology Printed Board Assemblies:
  To make the assembly of the PCB and the components as easy as possible.

Besides the IPC- and the airfield-standards the design also should comply with the RoHS [Material Measurements Laboratory, 2005], CE [CE, 2013] and EN [European Comittee for Standardization, 2008] directives to be able to be sold in different markets.

As the SAGA is a commercial product it has to comply with electronic safety standards. The IEC/EN60950-1 [International Electrotechnical Commission, 2005] standard is to be followed to ensure the SAGA design is safe to handle. This standard includes both mechanical and electrical specifications to ensure safety from both electric shock and fire.

### EMC/EMI - Electromagnetic Compatibility/Immunity

As manufacturers are responsible for a product not emitting too much unwanted signals, both conducted and radiated, the emissions has to be minimised. The reason for these demands are that unwanted signals could disturb or, in some cases, destroy other equipment connected to or just in the vicinities of the product. To ensure electromagnetic compatibility there are demands on the product of not just how much it emits, but also how much it can withstand.

To ensure the demands on EMC and EMI (EN 61000-6-4 and EN 61000-6-2) stated in the Product Requirements [Arnsby and Kjellsson, 2013b] are fulfiled, possible EMC problems are considered during the design phase of the project. The conducted emissions would mostly be sent out via the PSU. Since the PSU is to be an off-the-shelf product the EMC demands should be fulfiled by the chosen component. Immunity to conducted emissions is ensured by choosing tolerant components as well as designing the PCB in such way that most conducted emissions are sent to earth as quickly as possible.

To ensure immunity it is important to shield all wires connected to the PCB as they act as antennas. All shielding shall then be connected to earth to ensure a fast removal of unwanted signals. The radiated emissions are minimised by including EMC-filtering on all signals and feeds, more for the ones carrying a large current, in the design.

## 4.2 Lighting

To be able to evaluate the lighting system, the existing lighting had to be documented. A series of measurements regarding intensity, colour profile and flash frequency were made partly to determine that given specifications actually were fulfiled but mainly to be able to reproduce the effects.

### Current light source

The existing design of the SAGA use a 100W halogen light bulb emitting light through a 0.9mm gap which then continued through a focusing lens, see Figure 4.2. To get as much light as possible through the gap, the halogen light bulb have its focus point at the same distance as the gap is placed at.

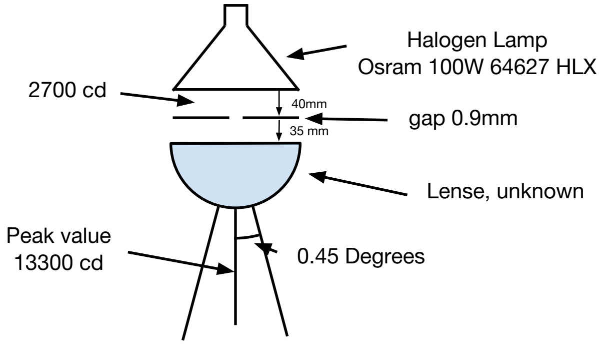


**Figure 4.2** The lamp and lens configuration on a SAGA unit.

### Luminous Flux

The luminous flux on the different intensity levels on the SAGA were measured with a lux-meter at a range of one meter from the mirror of the light source. This method of measuring with a lux-meter, which only measured the illuminance, give an easy calculation of the luminous flux (lm) as it is calculated using Equation 4.1 with the steradian $= 1m$.

$$lm = lux \cdot steradian \tag{4.1}$$

According to measurements of the SAGA unit in a lab the maximum luminous intensity is around 20000cd, see Appendix B.

### Effective Intensity

When working with flashing lights it is important to know of the term effective intensity. This term is needed as the intensity of a flashing light needs to be higher to be able to emit the same light during a short period of time as a steady light source does continuously.

To calculate the effective intensity the Blondel-Ray equation, Figure 4.3, was used. This equation basically use the intensity function of the product, integrated over one flash period and then divided by the period time $+0.2s$ as a visual time constant. This gives the effective intensity as approximately the mean intensity over one flash period.

$$I_e = \frac{\int_{t_0}^{t_1} I(t)\,dt}{0.2 + (t_1 - t_0)} \tag{4.2}$$

**Figure 4.3** The Blondel-Ray equation

In the case of the SAGA system the intensity function can be approximated by a square wave since the light source does not turn off and on. When using the Blondel-Ray equation with a square wave the only important parameters is the mean intensity, the flash time and the period time. As the old SAGA system have a too long flash and period time, discussed in Chapter 4.5, both these times have to be shortened. According to the Blondel-Ray equation, the new SAGA have the same effective intensity if both flash time and period time are halved.

## LED upgrade

As Safegate use LED lighting in most of their products it was discussed whether or not an LED upgrade was to be made on the SAGA. To be able to substitute the halogen light for a LED there are a few parameters that have to match.

First of all the luminous flux, secondly the colour profile, thirdly the visual characteristics and as a last criteria the focal point have to match if the same fitting is to be used. To determine if these parameters match, a series of different tests were conducted. First on the halogen light and then on a few different LED lights.

To fully understand the advantages and disadvantages between Halogen and LED a thorough investigation was made as seen in the paper "LED vs Halogen", in Appendix C.

The tests performed consisted of measuring the previously mentioned specifications. Measurements of colour profile and luminous flux were performed in a dark room at a defined range from the source to be able to compare the different light sources. The visual characteristics of the emitted light was measured at a distance of approximately 15m. From these measurements it was determined that the spread angle is 0.45° azimuthally, which is supported by the product specifications of the SAGA [Safegate International, 2013].

As concluded in the paper "LED vs Halogen" it is possible to substitute the halogen bulb with a LED module. This, however, will make mechanical changes to the optics of the SAGA's head necessary. Since changes of this magnitude would have required a lot of work to make sure the light characteristics did not differ from the original, the idea of LED substitution was excluded from the thesis work.

## 4.3 Electronics

The control boxes are the main parts that Safegate wanted upgraded, partly because the electronic parts are outdated but mainly because they stand for almost 50% of the production cost. The electronics included in the thesis work are the two different main boards, one for the master and one for the slave, as well as the stepper motor in each unit's head.

### Off-the-shelf Control Units

To ensure producibility it would have been good to use as many off-the-shelf products as possible, without raising the cost of the product too much. For the SAGA system this mean that a stepper motor control have to be integrated with programmable logic and a couple of different inputs and outputs. In addition to these parts something to control the different luminous flux intensities and a power supply unit is needed.

When searching the Internet for different options it was realised that a system containing all the mentioned details would have been more expensive than the 50% cost reduction allowed. The reason for it would have been that expensive is that the SAGA is a product combining a few not that unique subsystems into one small yet potent and quite unique main system.

It was decided that in the new design of the electronics system for the SAGA two main boards with micro controller, stepper motor driver, and communication necessities should be used.

### Power Supply Unit

When it comes to PSUs the two options are the use of transformers or switched-mode PSUs. Transformers have the advantage that they can handle overload and temperature better than switched-mode PSUs but on the other hand they are larger and need to be rectified with power loss as a result. Since the switched-mode PSUs does not have as much power loss it makes them more energy efficient and thereby more attractive in the design of the SAGA.

In the current SAGA units there are custom-made transformers with four secondary windings. Since the cost of these units are unknown it can only be estimated. By looking at off-the-shelf transformers with only one secondary winding and then comparing them to switched PSUs it was determined that the price does not differ enough to make it a factor in the choice.

### Dimming Possibilities

To ensure that the SAGA system does not blind the pilot, it need to have dimming possibilities. On the existing product it is possible to set three different predefined luminosities from the control tower by switching two relays in the master unit using a 48V feed. The new control system have to be able to handle this 48V input to be backward compatible.

What technique to be used for dimming the light depends on the power supply, for an ordinary transformer to be used the best way will be to use a triac on the primary side where the current is low and thus keeping the losses down. This will however require one transformer for the light and one for the rest of the system. Using two transformers will be too costly, if only one are to be used the current regulation for the light have to be done on the secondary side. Regulation on the secondary side can either be done by a triac directly on the AC or by other means after the rectification. The method to dim the light after rectification is the same as if a switched mode power supply would be used.

The easiest way to dim the light on DC is to use a MOSFET and control the intensity with PWM (Pulse-Width-Modulation). There are however a few drawbacks with this method. Switching the current on and off at high speed can cause the filament in the lamp to vibrate due to thermal stress and as a result the lamp may fail prematurely. Switching a high current in long leads will also emit electromagnetic interference.

Adding an inductor and a diode to the MOSFET will result in a simple buck converter which reduces the amplitude of the current flowing in the leads. This can be directly controlled by the PWM signal from the MCU (Microcontroller Unit), but in order to keep the inductor small a high switching frequency is needed. For this it will be better to use an IC (Integrated Circuit) specifically designed for buck converters and instead control the output voltage by changing the feedback divider to this chip.

### Microcontroller Unit

As the current MC68HC908GT16 [Freescale, 2007] micro controller is old and outdated it was substituted in favour of a Kinetis K10 [Freescale, 2012a]. For this application a much less potent MCU could have been used, but since the K10 is used in other Safegate products it simplifies production to use the same.

The Kinetis K10 is part of the Freescale Product Longevity [Freescale, 2013] which means that Freescale will support and produce the product for at least 10 years after product release. This was an important aspect when choosing components as one of the requirements are, to as far extent as possible, to ensure a long lifetime of the product.

As Freescale's K-series processors are pin-compatible, the design is not constrained to use only the specific MCU it is designed for. This is good as the production of different MCUs are being terminated at different times and thus will increase the products lifetime.

A substitution of MCU from the old MC68HC will require new software, but as there already were a lot of changes to be made in the software it was not considered a major issue.

### Stepper Motor

To turn the mirror in the SAGA unit a stepper motor is used, in the old design it is a stepper motor that no longer is produced. This makes the motor hard to get and unnecessarily expensive, when found.

A stepper motor is a motor that divides a rotation into small steps. The motor can by controlling the windings be told to either take one step forward, one step backward or stay at the current step. These kinds of motors are very good when precision is required in the rotations. As the SAGA needed an axis accuracy of 0.9° [Arnsby and Kjellsson, 2013b] the motor would have to take 400 steps per turn.

The existing motor is a SB6500 R.460 [Sonceboz, 2001], a double shafted unipolar stepper motor that take 200 steps per turn. Since the motor driver is a full H-bridge it is connected to control the motor as a bipolar instead of unipolar, hence making the criteria of a unipolar winding uncalled for. Since 400 steps are needed for the angular resolution between each step, the motor is half stepped using the stepper driver.

To ensure backward compatibility the motor used in the new design have to match as close as possible to the old specifications, both from a physical and electrical perspective.

### Heating Resistor

To ensure that the components in the design work as intended when the temperature decreases, a heating resistor is installed in the head of each SAGA unit. If only components that can handle -40°C are chosen during the design phase the heater is not needed in the electronics box to fulfil the requirements. However, there should be the possibility to mount the heating resistor if proper operation in lower surrounding temperatures are required.

The heating resistor uses the material's curie point to control the temperature. When the temperature rise above 50°C the material's resistance increases and thus decreases the current through it [Vulcanic, 2012]. The heating resistors are connected on a different phase from the rest of the electronics system to always have the heaters on even when the unit are not.

To be able to get a hint of how much power the heater need to ensure the temperature stays above what the components can handle, the calculations in Figure 4.4 were used. The calculations seen in Figure 4.5, indicate that approximately 10W of heat will be enough to hold the temperature 20°C above surrounding temperature.

$$k = \text{Heat transfer coefficient}\,(\frac{W}{Km^2})$$
$$\Delta T = \text{Temperature difference}\,(K)$$
$$A = \text{Conducting surface area}\,(m^2)$$
$$P_h = \text{Power needed}\,(W)$$
$$P_h = 2 \cdot (\Delta T \cdot k \cdot A)$$

**Figure 4.4** Equations used to determine power needed to raise temperature in enclosure [Hammond, 2012].

During empirical studies of the heating of an enclosure it was noticed that a heating resistor of a lot more than 10 W would be needed to get the wanted raise of temperature. This is explained by the heat from the resistor not being transferred to the air fast enough resulting in the heating resistor limiting its own power usage due to over temperature detection.

$$k = 1.23\,(\frac{W}{Km^2})$$
$$\Delta T = 20\,(K)$$
$$A = 2 \cdot (0.324\,m \cdot 0.164\,m + 0.164\,m \cdot 0.100\,m + 0.324\,m \cdot 0.100\,m) = 0.2039\,(m^2)$$
$$P_h = \text{Power needed}\,(W)$$
$$P_h = 2 \cdot (0.2039\ m^2 \cdot 20\ K \cdot 1.23\ \frac{W}{K \cdot m^2}) = 10.03\ W$$

**Figure 4.5** Power needed to heat enclosure 20 degrees above surrounding environment.

## 4.4 Communication

Communications in the SAGA units are limited to the communication between master/slave and the communication between the master unit and the control tower. As backwards compatibility is a demand, the new design have to be compatible with the old communication systems.

### Master ↔ Slave

In the old system the only processor controlling the units is located in the master unit, all signals needed for control of the light, motor as well as fault signals, are sent in parallel by cable to and from the slave, see Table 4.6. This forces the installation to use unnecessarily many wires in the cable between the units.

| Master → Slave | Slave → Master |
|---|---|
| Lamp on/off | Proximity sensor |
| Lamp intensity | Lamp current detector |
| Stepper motor clock | |

**Figure 4.6** Signals between the SAGA master and slave units

### Master ↔ Control Tower

The signals that come from the master unit to the control tower, as seen in Table 4.7, are actually just the master short circuiting the two cables coming from the tower concerning either master- or slave-fault. When the control tower signal the SAGA units what brilliancy level they should use, the 48V signal directly drive relay that connects the different windings the transformer controlling the feed to the halogen light bulb.

As the transformer is to be substituted by a switched-mode PSU this way of controlling the brilliancy is no longer a possibility. Instead proper voltage regulators have to be designed and implemented on the board for the different voltage levels.

| Master → Tower | Tower → Master |
|---|---|
| Fault Master | Lamp on/off |
| Fault Slave | Luminous intensity |

**Figure 4.7** Signals between master and control tower

## 4.5 Software

Since it is crucial that the SAGA units maintain the correct way of operation the software have to continuously perform tests to ensure the system is running according to design.

### Flashing Frequency

The old specification for SAGA states that it flashes with a frequency of 1 Hz, but the actual frequency measured on the devices is $1/1.9$Hz. When looking through the code for the old design it became clear that the code used a predefined table for the delays between steps with the stepper motor. This table also exists in the old French documentation with the only difference that in the C-code the delay table is called twice in every step taken by the stepper motor. By doing this the code effectively decrease the frequency from the $1/0.97$ Hz calculated using the table to $1/1.94$ Hz.

A French expert on the SAGA units informed that according to a test on a military base the pilot said that when using the SAGA for azimuthal guidance there was too much time between flashes to make a smooth decent. This can be explained by it actually flashing with less than half the frequency it was supposed to due to the programming error previously described.

The frequency of 1 Hz was chosen as ICAO recommends 60 to 120 flashes per minute on approach lights [ICAO, 2010]. To have time for delay between flashes the lower frequency will suffice in the case of SAGA. These flash frequencies are recommended as commercial airplanes rarely exceeds approach speeds of above 300km/h [Boeing, 2011]. When approaching with a speed of 300km/h an airplane moves at 83m/s. The SAGA is specified to be visible for about 18km, this gives the pilot 3.6 minutes or 216 flash periods, to maintain the correct approach axis.

When changing the flashing frequency it is necessary to make sure the effective intensity does not differ too much. The general way of computing the effective intensity, $I_e$, in the world of aeronautics is, as previously mentioned, by using the Blondel-Ray-equation, see Figure 4.3 [Solid State Lights, 2011]. This will be discussed further in the chapter about rotation speed.

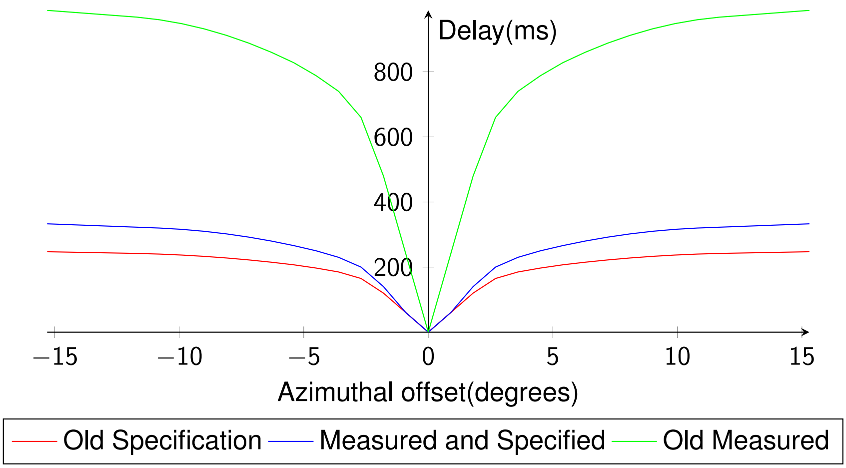


**Figure 4.8** Delay between flashes depending on azimuthal offset.

### Time Between Flashes from Master and Slave

For the pilot to be able to determine how azimuthally far from the approach axis an approaching airplane or helicopter are, the delay between the flashes from the two SAGA units increase the further away from the approach axis the pilot is. When within a $\pm 0.45°$ angle from the approach axis the flashes are seen simultaneously. If between $\pm 0.45°$ and $\pm 15°$ the flashes have an exponentially rising delay from 60ms at just outside $\pm 0.45°$ to 330ms when close to $\pm 15°$.

The delay of 60ms was chosen as it is well above what the human brain should be able to notice [United States Navy, 1990], but still far away from the maximum delay. 330ms was chosen as the maximum delay as this is $1/3$ of the flashing frequency and by that distinctly noticeable from the $2/3$ of the flashing period when no flashes are seen.

To ensure the pilot is aware of the axis inaccuracy of the aircraft the delay have to rise fast from 60ms to closer to 330ms as shown in Figure 4.8.

### Rotation Speed

To be able to handle the flashing frequency of 1 Hz and the axis accuracy of ±0.45° the stepper motor have to be turned 400 steps in one second. This can be done in a number of ways, but since the delay between the two flashes have to be between 60ms and 330ms and rising fast a table for the different step delays was produced. The table used to achieve these delays is shown in Table 4.1.

| **Step** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13-200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Delay** | 30 | 40 | 30 | 15 | 10 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1.3 |

**Table 4.1** Delay between steps for stepper motor to ensure the delay between flashes stays between 60ms and 300ms. Since the stepper motor takes half steps the table was used twice per turn.

While investigating the current product the calculations did not at first give a clear knowledge about how it works and what parameters are important. To fully understand how the system is working a simulation program was written, see Figure 4.9. For simplicity and speed this was written in python. In the simulation two light beams turn around at a fixed distance simulating the end of a runway. The rotation speed was set using the step delay table in Table 4.1. An airplane can be placed by mouse click somewhere in the approach corridor and using collision detection the corresponding light is shown when the beam hit the airplane. The time between when the beams reach the airplane is calculated and shown. This confirms the 60-330ms delay specified in the requirements by using the calculated table.

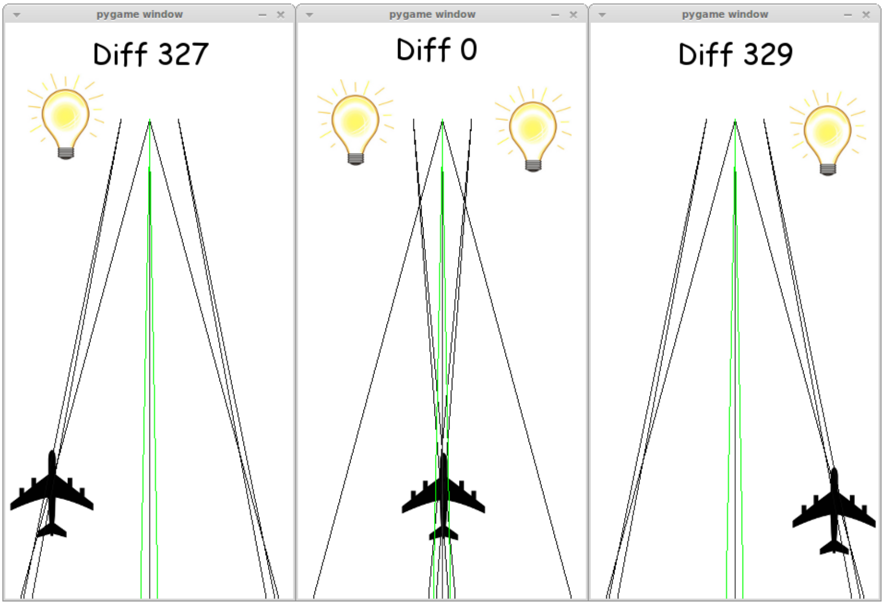


**Figure 4.9** Simulation of the SAGA, the delay between flashes are shown between the light bulbs in the image. The difference between the Diff in the two outer images is because the simulated airplane is positioned manually.

As previously discussed in Chapter 4.5, the effective intensity of the emitted light differs depending on the flash period and flash length as well as intensity. In the SAGA system where the delay between steps differ, the effective intensity differs depending on the azimuthal offset from the approach axis. The closer to the approach axis, the higher effective intensity. The change in effective intensity is shown in Figure 4.10.

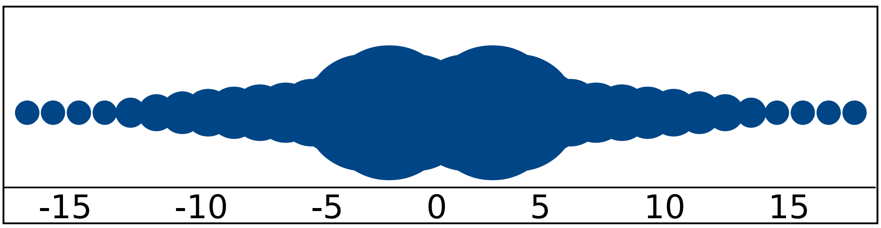


**Figure 4.10** Effective intensity as a function of the azimuthal offset.

### Fault Handling

When a fault is detected both units halts. The remote control tower is then notified via "dry contacts" (basically just short circuiting two wires connected to the control tower) that there is a fault. The same fault is visualised using LEDs on each SAGA unit.

As both units should stop at any error it is important to determine how to detect faults. In Table 4.2 the faults that were necessary to detect to ensure a working product regarding the product requirements [Arnsby and Kjellsson, 2013b] are shown. The detection of the different faults are thought of during the design phase, both electronics and software, and all faults are checked for at every revolution of the mirror.

| Fault in | Detection |
|---|---|
| Stepper motor | Proximity sensor and stall detection |
| Lamp | Current detection feedback to MCU |
| Communications | Sync signal between Master/Slave |

**Table 4.2** Faults in the SAGA units and how to detect them.

## 4.6 Environmental Requirements

### Thermal and Weather

As the system is to be installed outdoors and operational all year around in different parts of the world it is decided to follow the same specifications regarding temperature as for the PAPI (Precision Approach Path Indicator) [Federal Aviation Administration, 2011], which is another kind of approach guidance system. This means withstanding heavy rain and a temperature range of -40°C to 55°C. The environmental requirements are fulfiled by keeping the electronics in an IP67 classified box and using a heater if there are components not specified to handle the cold temperatures.

### Lightning and Surges

To fulfil the requirements from FAA-STD-019e [Federal Aviation Administration, 2005] regarding lightning, all inputs have to be able to handle surges of up to 10kV and 5kA. This has to be considered during the design phase to ensure that proper surge protection is included in the finished product.

### Chemical Resistance

Since there are a few different corrosive chemicals used on airfields, such as deicing fluids and jet fuel, the casing of the electronics has to be resistant to corrosion. The solution to withstand as much as possible is to use a casing made of fibreglass reinforced polyester [Rolec Enclosures, 2011].

## 4.7 Requirements, Verification and Validation

To make sure all market demands are met by the technical design a Product Requirement document is written [Arnsby and Kjellsson, 2013b]. This document was used during the design phase to ensure that all functionality needed is implemented.

After the design phase it has to be possible to ensure the requirements are fulfiled. To be able to do this a Verification plan [Arnsby and Kjellsson, 2013c] was written in which tests were specified for all requirements in the Product Requirement document. All tests have criteria that have to be met by the proposed design in order to pass the Product Verification.

When the prototype is finished it have to be validated that it actually does what it was intended to do. For this a Validation plan [Arnsby and Kjellsson, 2013a] was drafted. This document ensure that the market demands on the product are fulfiled by formulated tests and criteria based on the demands.

# 5

# Design Phase

## 5.1 Use of Existing Safegate Components

The same processor architecture as used in other products is to be used, but to use an existing PCB is out of the question, mainly because the design would need a lot of different components that Safegate do not have on one PCB. This would have resulted in at least one additional PCB and it is cheaper to put everything on one.

## 5.2 Lighting

The lighting theoretically should not have been altered noticeably, according to calculations based on the Blondel-Ray equation. So the main thing that need to be tested, after the new design is implemented, is to make sure the intensity levels fulfil the requirements.

## 5.3 Electronics

The concluded design structure of the electronics box is shown in Figure 5.1. This structure is very similar to the one from the old SAGA system, with the exception that the connection between the master and slave have been optimised since both units contain an MCU. Even though the theoretical structure is not that different in the new design, the electronics have taken a big leap forward. Instead of using two different boards for the master and slave one single board will be used. By using switches on the board it can be configured to run as either master or slave. By using the same design for both master and slave the production volume of this board increases and thus lowering the cost.

This design ensure compatibility with the old mechanical design of the SAGA but still give room for optimisation in the electronics design.

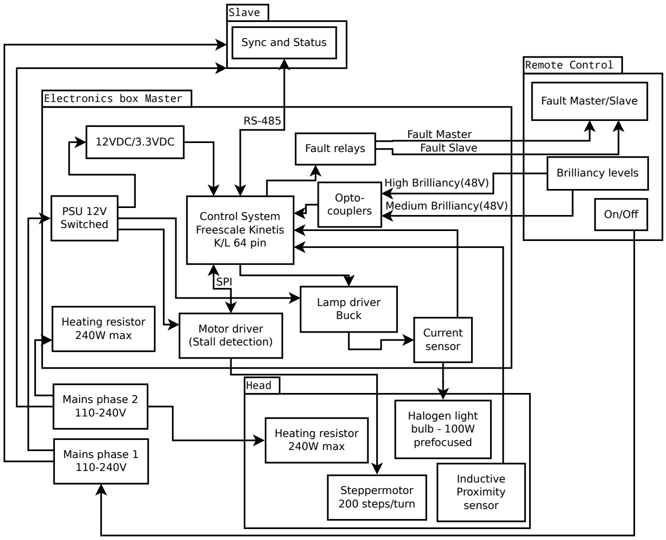


**Figure 5.1** Design structure of electronics system in SAGA.

## Electronic Safety

To comply with IEC/EN60950-1 [International Electrotechnical Commission, 2005], a standard regarding the presence of mains supply on the PCB, 2.5mm isolation between Line and Neutral and 5mm isolation between main lines and Earth are needed. Even with these safety concerns it is not intended to open the lid of the electronics box while the mains supply is connected.

## Power Supply Unit

For the electronics design of the SAGA system it was decided that a switched-mode power supply should be used. The process of determining which PSU should be used was quite simple. From the thermal and surge requirements specified for the SAGA system the number of PSUs possible to use in the system are limited.

The PSU chosen, a "VI Brick AC Front End" from Vicor [Vicor, 2013], combined the thermal and power needs in a small and neat PCB mounted PSU. Compared to other PSUs the VI Brick is five times more expensive, but since it is PCB mounted all the surge protection could be mounted on the PCB as well. The PCB mounted surge protection cost about a tenth of the price compared to buying an external commercial surge protector. By having it all mounted on the PCB the manual assembly work was decreased by approximately an hour.

### Switching Regulator

As the PSU supplies a voltage of 48V it have to be transformed to 12V for the light bulb, 12V for the stepper motor and 3.3V for the MCU. This is done by using two buck converters.

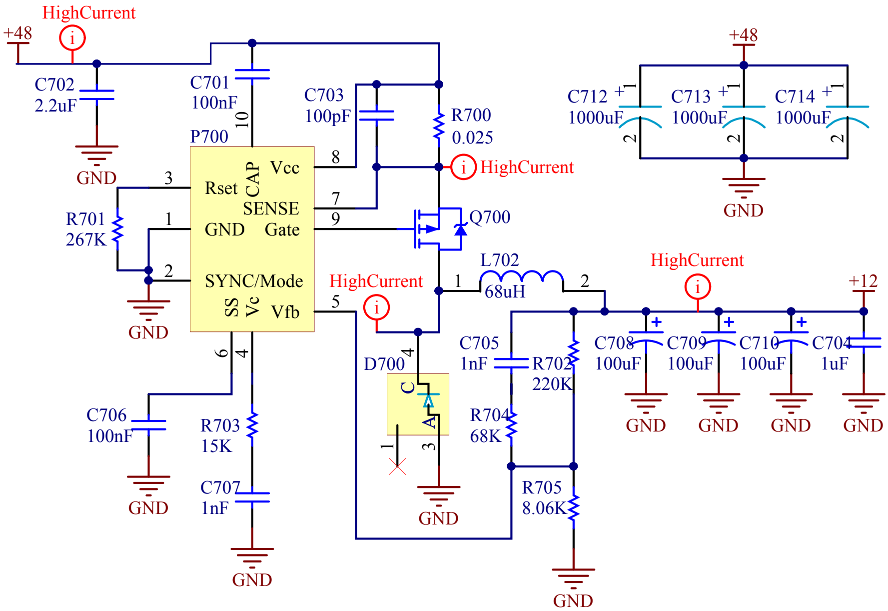


**Figure 5.2** 12V Switchregulator.

To generate the 12V a LTC3824 [Linear, 2011] is used, connected as in Figure 5.2. This regulator is also used for driving the stepper motor and a few communication relays as well as supplying the switch regulator in Figure 5.3 that generates 3.3V for the MCU. The same circuit as for the 12V is used to drive the lamp. This regulator provided the Halogen light with current. The feedback divider can be changed through a set of MOSFETs and thus setting different output voltages, see Figure 5.4. These are controlled from the MCU to change the intensity of the lamp.

### Surge Protection

The surge protection in the design is very important as the SAGA system is going to be mounted on open fields. To be able to handle the high transients in this environment much care have to be taken, all inputs and outputs need

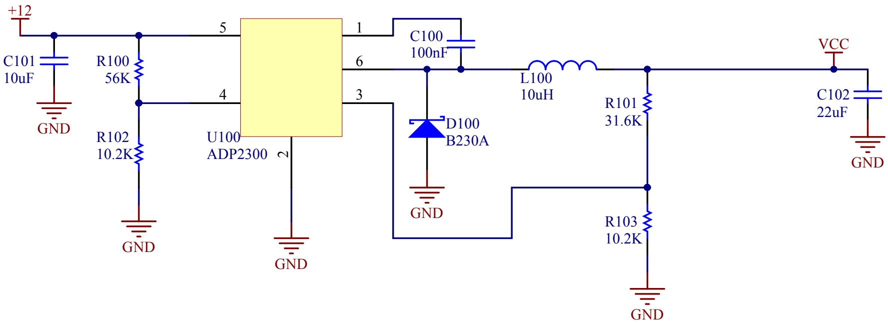


**Figure 5.3** 3.3V Switchregulator.

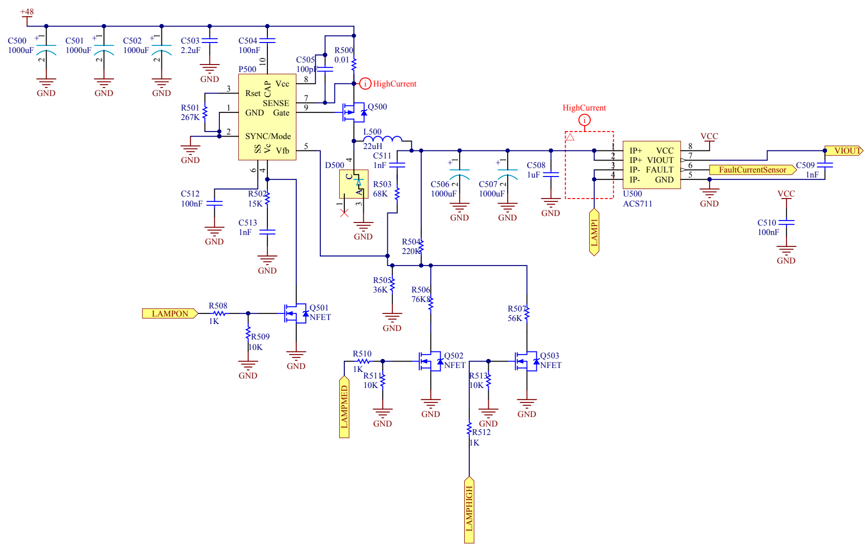


**Figure 5.4** Lampdriver.

to be protected from high voltage surges. The lines that are vulnerable are mains supply, tower communication and Master/Slave communication. As the requirements are quite different on these lines the protective circuits differs.

For the mains input a three stage protection system consisting of a MOV (metal-oxide varistor) a common-mode choke inductor and a GDT (gas discharge tube), as shown in Figure 5.5, is used. When the transient enters the circuit the voltage on the MOV raise which cause it to start conducting, this makes a large current flow through the inductor. The inductor's impedance

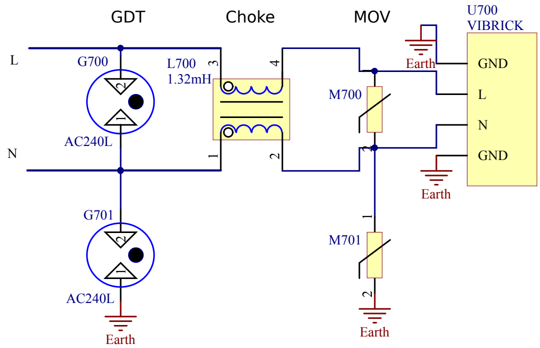


**Figure 5.5** Surge protection for PSU

forces the voltage over the GDT to rise to the point where it starts to conduct.

When the transient ends the GDT stops conducting and the circuit goes back to normal operation. The GDT used is specially chosen to stop conducting even when the main lines supply power, a standard GDT does not stop conducting after the transient is over and would cause a short circuit on the mains line.

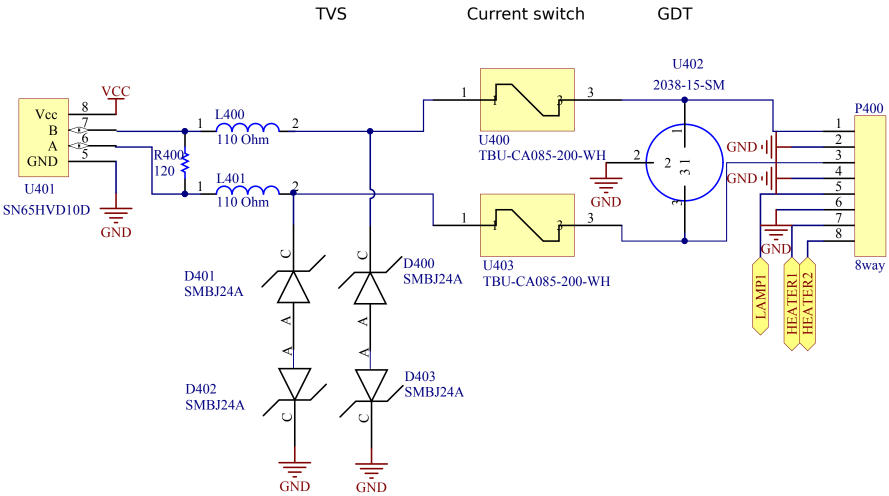


**Figure 5.6** Surge protection for Communication

As protection for the communications, a large inductance could not be used as it would disrupt the communication. Instead a specially developed current switch is used which will stop conducting when a large current is detected through it. Testing showed that the current switch turn off within 50nS if a high current is detected. The protective schematic consisted of a TVS (Transient Voltage Suppression diode), a current switch and a GDT Figure 5.6.

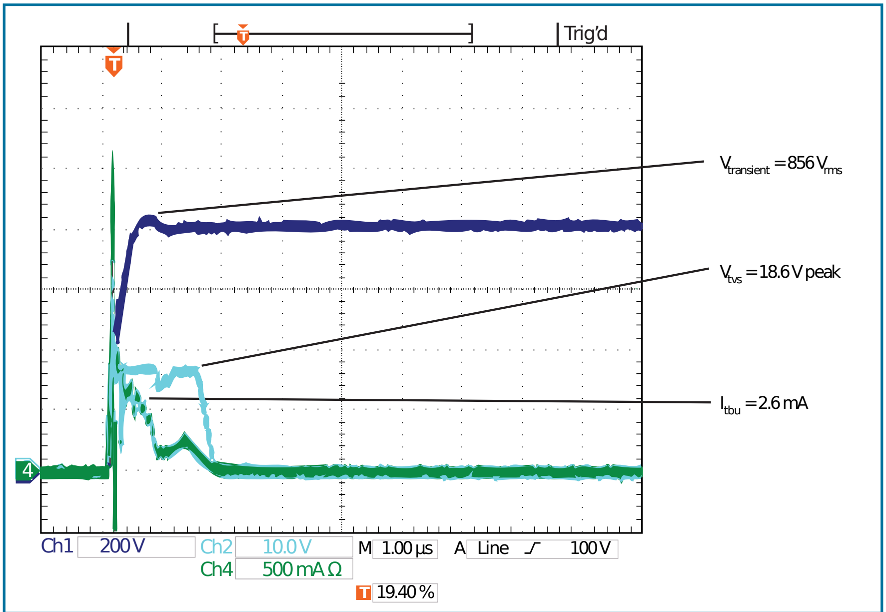


*Figure 8: 0.5 µs $t_{rise}$/700 µs $t_{fall}$ Surge*

**Figure 5.7** Graph of transient entering the surge protection, from Bourns Appnote [Bourns, 2011]

When the transient enters the circuit, the TVS clamps the voltage to protect the inputs, which then redirects the surge to ground. The increased current triggers the current switch to stop conducting, the now high impedance state of the lines cause the voltage to rise above the GDTs trigger level and forces it to short circuit the lines. In Figure 5.7 the transient is shown entering the protective components. When the transient is over, the GDT stop conducting and the current switch starts conducting again which restores the circuits normal operation.

## 5.4 Hardware Design

When all components and solutions for different problems have been chosen, a schematic of the design was done to be able to produce it. To meet the temperature requirements only components that can withstand -40 °C were chosen. The design of the hardware was done in the CAD-software called "Altium Designer" [*Altium Designer*]. As the use of this software is new to the company, a course to learn Altium Designer is given to all electrical engineers as well as master thesis students. In Altium Designer everything from designing the components to drawing the schematic and finally to design the PCB is done. To make sure the electronics fitted in the proposed casing a 3D drawing of the PCB with the components mounted inside a 3D model of the casing is produced, see Figure 5.8.

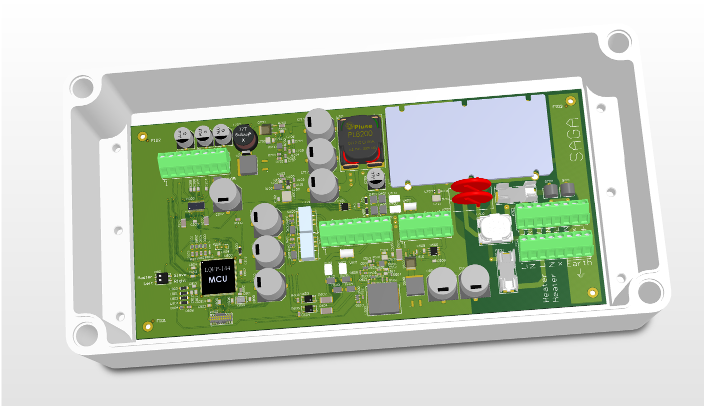


**Figure 5.8** 3D generated picture of the design.

## 5.5 Software

As showed in Figure 5.9 the software design consists of three different states, the initial state, the running state and the fail state. The initial state runs when the units turn on and performs a sanity check of the system to make sure everything works. The running state checks that the system actually is running as intended as well as communicates with the other unit. In the fail state both units turn off immediately and starts to send fault signals to remote management system as well as flashes the fault LEDs on the mainboards.

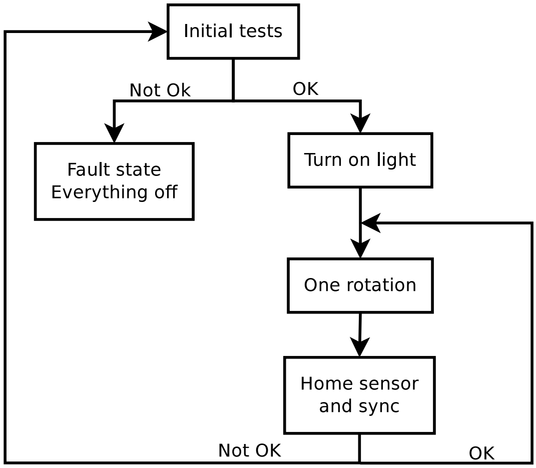


**Figure 5.9** Simplified structure of the software of the SAGA units.

## 5.6 Communication

The communication between the master and slave is decided to be upgraded a lot. From just sending the actual signals back and forth and hence not needing two MCUs, to having one MCU in each SAGA unit and thereby being able to use a more sophisticated protocol of sending signals. RS-485 [Texas Instruments, 2008] was decided to be used as this standard uses signals sent in a differential pair and thereby is resilient to electromagnetic noise.

Signals sent to and received from the remote management system were kept the same but extended to be able to handle anything from 48V to 230V so as not to limit the tower to only use 48V as the former product.

## 5.7 Synchronisation and control of Rotation

As there always are minor differences in the clock frequencies for each MCU some kind of synchronisation is needed. The first approach is to use the serial communication to force the units to wait for each other on each revolution. For this to work one of the units have to wait for the other. Stopping the motion of the mirror adds stress to the mechanics that is unwanted. To get past this a better control strategy is needed.

Instead of the sporadic synchronisation, about once every second, it is decided that the master should send a synchronisation clock on the differential lines to ensure that the mirrors are synchronised. To be able to get status from the slave unit, the communication line changes from being a clock line to be an asynchronous UART during 10 steps when the mirror is pointing backwards. While in this mode the two units exchange status information and lighting commands. During the steps before the mode changes the slave measures the length between the synchronisation clock to determine what delay it should use during the 10 steps of communication.

By using this method the the mirrors rotation is always synchronised during the critical steps when the mirror is pointing forward and the matched delay makes the transition between the modes seamless. This, however, only controls that the mirrors take their steps simultaneously, to make sure the mirrors is pointing in the correct direction the master and slave unit each uses its rotation sensor to control the position. When the system is running the mirrors need to be at the exact same angle, if it is of by just one step (0.45°) the system will give the pilot wrong information about the approach. Therefore if the sensors does not trigger on the precise correct step the units are halted and a new initiation procedure is done.

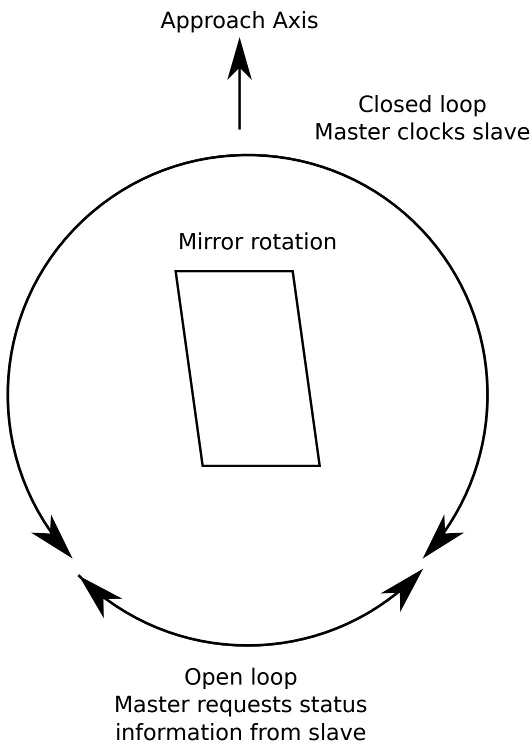


**Figure 5.10** Synchronisation during rotations.

## 5.8 Documentation

Some of the old documentation of the SAGA systems do exist in English, but the test procedures are all in French. To be able to use the new control box in the product some documentations have to be updated. The work to update the actual documents is up to the documentation department, but for them to be able to update the documentation it has to be stated what actually needs updating.

There is assembly drawings that need to be substituted, some assembly instructions that need to be updated, the user/installation manual and some of the testing procedures have to be changed. The specifications of the SAGA only have some minor spelling mistakes that need to be updated.

## 5.9 Proof of Concept

While waiting for the prototypes to be manufactured and to be able to test the software on the real units two development kits where used along with the old drivers and sensors to build a working SAGA system. The development boards consist of a K40 Tower [Freescale, 2010] and Freedom KL25Z [Freescale, 2012b], which both are in the same processor family as the chosen MCU.

## 5.10 Prototype

Upon receiving the prototype boards verifications of every different part of the board started. Voltage regulators, stepper driver, communication ports and the MCU where all checked to be working according to the design.

Unfortunately not everything that gets produced is perfect. The voltage regulator feeding the lamp have a MOSFET that overheats when put to stress tests, the voltage regulator feeding the 12V system has some badly calculated resistors so it does not feed 12V and the relays are polarized the other way than drawn on the PCB. These things are all manageable by some small fixes on the prototype board, but needs redrawing of the PCB before any more units can be produced.

During the tests the lamp driver was heating up causing the MOSFET to fail, this needed a deeper investigation as the driver of the lamp is one of the most important parts of the product. The results of the investigation is that a synchronous buck converter is to be used, see Appendix A.

# 6

# Resulting Product

During the thesis work two prototypes of the control box were built to be able to substitute the electronics in an old SAGA system. When the prototypes were finished and working according to design they were tested and compared to the old system, from a user perspective but more importantly from a functional perspective.

## 6.1 Lighting

As the new electronics box does not alter anything regarding the emitted light's colour or profile, the main thing to check is that the luminous flux is comparable to the old units.

When calculating the different intensity levels possible to achieve by different voltages from the regulator, the ones in the old system are used as reference. This means that theoretically there is no difference in the luminous flux of the intensity levels. After making measurements of a new SAGA unit besides an old SAGA unit it is clear that the luminous intensity do not differ outside the limits stated in the product verification plan see appendix B for measurements.

## 6.2 Risk Assessment of Lifetime

All the parts used in the product are reviewed in terms of their lifespan. As it is hard to get manufacturers to guarantee the lifetime of their components, the components used in the prototype are chosen to be substitutable by similar components from other brands. The components that do not have any easy substitutes are the PSU and the current switches in the surge protection. These do not, according to a quick market research, seem to be abandoned any time soon.

## 6.3 Economical Savings

Comparing different parts of the electronics box is not possible as there does not exist any BOM for the old box. But when comparing the cost of the prototype, which is high compared to the final production cost, to the old total cost it is clear that the reduction goal of 50% is achieved.

As well as being cheaper to produce, the new design is cheaper to assemble. The electronics box has fewer wires and components to manually install both between the boxes and inside the boxes.

## 6.4 Regulation Compliance

When writing the product requirements for the SAGA system it is realised that the old electronics box do not fulfil the regulations from FAA och ICAO. This is due to the product being developed before many of the regulations used today were drafted.

With the new electronics box the SAGA system is not possible to certify with for example STAC, as no dedicated regulations exist for the product. But at least it is possible to claim that it fulfils the same requirements as other lighting systems built for approach guidance as well as the general regulations regarding airfield lighting.

During the project period there is not enough time to go to a certified EMC testing facility to see if the system was CE compliant, but fortunately there are possibilities to make some basic EMC measurements at the Department of Measurement Technology and Industrial Electrical Engineering at LTH. Measurements in their laboratory gave the indication that the new SAGA electronics should fulfil the EMC regulations required for the CE marking.

## 6.5 Final Testing and Verification

When the prototypes are working as intended the whole system goes through the previously written validation- and verification-plans.

Communication between the units is tested with a 90m cable rolled up in a big pile, in order to make some kind of worst case scenario, with great success. All communications work as intended even under these circumstances. The parts that the system can detect failure in is rotation, lamp and communication. All these faults halt both units and emits error code to the control tower.

To ensure the system reacted as specified in all imaginable cases a compilation of possible fault scenarios where written. Each fault was then induced to a SAGA prototype system and some minor fixes in software has to be done to fulfil them all.

As a last verification the luminance of the emitted light has to be measured in order to verify that the new control system do not change the characteristics of the SAGA. These measurements are done in the same way as during the reverse engineering of the product in order to be comparable. Comparison of the measurements of the new and old control units concluded that the luminances of the emitted light is equal with old and new control system.

# 7

# Further Improvements

## 7.1 Productification

To make the product ready for production, the design has to implement the fixes that are done to get the prototype working. The changes in the PCB and schematics are done, but have not been tested. So to make sure the new PCB actually will work a second batch of prototypes has to be made.

After the second batch of prototypes have been produced and tested, the assembly instructions and testing procedures need to be updated to ensure the produced units will work as intended.

When the electronics for the control system is confirmed to be working as intended a mechanical structure used to mount the box to the SAGA unit needs to be designed. This could be done by modifying the current mounting bars to fit the new box.

In order to make the production of the SAGA better, a test rig will have to be developed. This test rig should test the sensors, the motor, the lamp driver and should flash the MCU with the correct software.

## 7.2 Electronics Improvements

To further improve the electronics of the SAGA system a redesign of the head and possibly skipping the requirement of backward compatibility. A restructuring of the head could lead to a LED version of SAGA. To drive the LED a current controller is needed. A PI regulator can be implemented as current control using the current sensor, currently used as a sensor to ensure the lamp works as intended, as feedback and controlling the duty cycle of the Synchronous Buck Converter. If the backward compatibility demand is overseen the communication with the control tower could be made to work in other, possibly easier, ways.

## 7.3 Over All Improvements

While looking into the electronic parts of the SAGA units it is realised that many parts are still the same as from the prototyping phase. Many parts could be slightly redesigned to optimise them for production. The mechanical redesign and review of standard parts would cut the production cost for the whole unit.

To get the product more like other Safegate products, the light source should be converted to LED. This would not make the production cost much lower and would not make the maintenance much cheaper, but it would complement the product portfolio to a full LED set.

# Bibliography


Altium. *Altium Designer*. URL: http://altium.com/ (visited on 04/10/2013).

Arnsby, J. and M. Kjellsson (2013a). *SAGA - Product Validation plan*. Safegate International AB.

— (2013b). *SAGA Product Requirements version 0.2*. Safegate International AB.

— (2013c). *SAGA Product Verification plan*. Safegate International AB.

Boeing (2011). *Approach speeds of boeing commercial series*. URL: http://www.boeing.com/commercial/airports/faqs/arcandapproachspeeds.pdf (visited on 02/21/2013).

Bourns (2011). *Handling transient threats in rs-485 systems*. URL: http://www.bourns.com/data/global/pdfs/Bourns_RS-485_AppNote.pdf (visited on 07/03/2013).

CE (2013). *Ce marking*. URL: http://ec.europa.eu/enterprise/policies/single-market-goods/cemarking/index_en.htm (visited on 05/06/2013).

European Comittee for Standardization (2008). *En 50490:2008 - electrical installations for lighting and beaconing of aerodromes*.

Federal Aviation Administration (2005). *FAA:FAA-019e - Lightning and surge protection, grounding, bonding and shielding requirements for facilities and electronic equipment*. URL: https://faaco.faa.gov/attachments/STD-019e2.pdf (visited on 01/30/2013).

— (2011). *FAA: FAA-AC-150-5345-28G Advicory Circular for PAPI*. URL: http://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5345_28g.pdf (visited on 04/08/2013).

Freescale (2007). *Datasheet MC68HC*. URL: http://cache.freescale.com/files/microcontrollers/doc/data_sheet/MC68HC908GT16.pdf (visited on 03/03/2013).

Freescale (2010). *TWR-K40X256 Tower Module User's Manual*. URL: http://cache.freescale.com/files/32bit/doc/ref_manual/TWR-K40X256-UM.pdf (visited on 04/25/2013).

— (2012a). *Datasheet Kinetis K10-series, rev 4.* URL: http://cache.freescale.com/files/microcontrollers/doc/data_sheet/K10P144M120SF3.pdf (visited on 03/14/2013).

— (2012b). *FRDM-KL25Z User's Manual, rev 1.* URL: http://cache.freescale.com/files/32bit/doc/user_guide/FRDMKL25ZUM.zip?fpsp=1 (visited on 04/25/2013).

— (2013). *Freescale longevity program*. URL: http://www.freescale.com/webapp/sps/site/overview.jsp?code=PRDCT_LONGEVITY_HM (visited on 02/27/2013).

Hammond (2012). *Heating Products*. URL: http://www.hammondmfg.com/pdf/Heaters.pdf (visited on 05/07/2013).

ICAO (2010). *Icao annex 14*. URL: http://legacy.icao.int/fsix/_Library%5CManual%20Aerodrome%20Stds.pdf (visited on 01/30/2013).

International Electrotechnical Commission (2005). *IEC/EN 60950-1 Information technology equipment - Safety Regulations*.

Linear (2011). *Datasheet LTC3824, rev G.* URL: http://cds.linear.com/docs/en/datasheet/3824fg.pdf (visited on 02/12/2013).

Material Measurements Laboratory (2005). *Support of industry compliance with the eu directive on restriction of certain hazardous substances (rohs)*. URL: http://www.nist.gov/mml/csd/inorganic/rohs.cfm (visited on 04/12/2013).

Randall Munroe (2011). *How Standards Proliferate*. URL: http://xkcd.com/927/ (visited on 06/14/2013).

Rolec Enclosures (2011). *Material Specifications Enclosure*. URL: http://www.rolec-enclosures.co.uk/technical/Material_Specifications.htm (visited on 02/28/2013).

Safegate International (2013). *Product description SAGA*. Safegate International AB. URL: http://www.safegate.com/tibet/template/media%2CMediaObjectFile.vm?siteid=1040&objectid=2521&size=large.

Solid State Lights (2011). *At what cost will leds replace flashtube lights?* URL: http://airbornelights.wordpress.com/lighting-technology/at-what-cost-will-leds-replace-flashtube-lights/ (visited on 04/26/2013).

Sonceboz (2001). *Datasheet Stepper Motor SB6500*. URL: http://www.astelweb.com/download/pdf/prodotti/motoripp/6500/6500-20.pdf (visited on 03/01/2013).

Texas Instruments (2008). *RS-485 Specifications*. URL: http://www.ti.com/lit/an/slla272b/slla272b.pdf (visited on 04/17/2013).

United States Navy (1990). *Frequency of a flashing light as a navigational range indicator*. URL: http://www.dtic.mil/dtic/tr/fulltext/u2/a221924.pdf (visited on 02/12/2013).

Vicor (2013). *Datasheet VI-Brick AC Front End*. URL: http://cdn.vicorpower.com/documents/datasheets/vibrick/ds_FE175D480C033FP-00.pdf (visited on 04/03/2013).

Vulcanic (2012). *Datasheet Heater Vulcanic 3941-21*. URL: http://asp.zone-secure.net/v2/index.jsp?id=4524/5896/27500&lng=en (visited on 03/01/2013).

Waterfall Model (2013). *The V-Model development framework*. URL: http://www.waterfall-model.com/v-model-waterfall-model/ (visited on 04/23/2013).

# A

# Lamp Driver Experiences

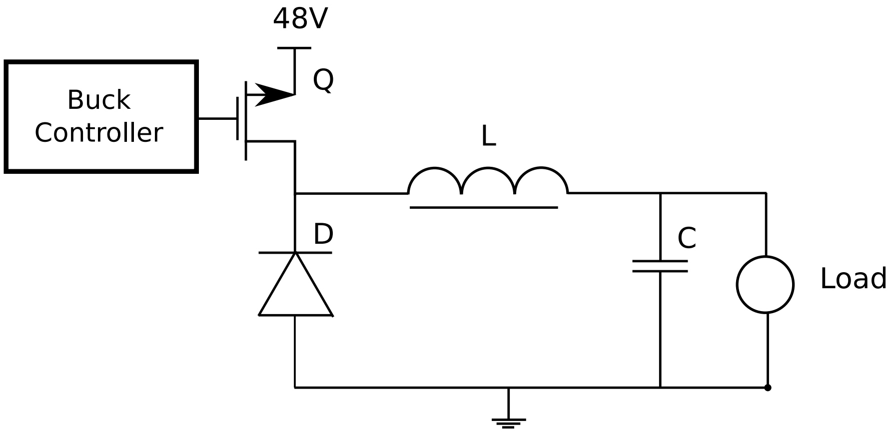


**Figure A.1** Buck Regulator.

The original design for the lamp driver used a standard Buck converter topology, see Figure A.1, with a controller IC from Linear, the LTC3824, as it uses an external MOSFET for the power. By choosing a big enough MOSFET it could handle the currents needed for the halogen light. To validate the design LT-Spice was used to simulate the circuit with different values for the inductor and feedback. With good results from the simulation the boards were produced.

When testing the driver a few issues were found, during the design the diodes voltage rating were chosen to 15V as the highest output voltage would be 12V. This is not accurate as the diode will get the whole input voltage of 48V in the reverse direction when the converter is in open mode. This error was corrected simply by substituting the diode with one with the correct voltage rating.

Even with the new diode there were still problems with the circuit, the main problem was temperature rise in the MOSFET and diode. Measurements indicate that the switching induces noise causing the Buck controller circuit to malfunction. The result was irregular switch interval for the MOSFET with one long period followed with a few short. The short periods does not carry much current to the light but generates the same amount of switch losses as the long periods.

The root of this problem is most likely the PCB design. By analysing the design and moving some components this switching noise could be minimised. Even with this problem fixed the diode will still heat up, the large difference between input voltage and output voltage will make the diode carry current for almost the whole switching period.

The diode with correct voltage limits and lowest forward voltage was chosen to minimise loss but this still has around 0.5V forward voltage. When driving the lamp at full power 8A will be flowing through the diode causing a power loss of $0.5V * 8A = 4W$ that have to be led away and would require a large heatsink.

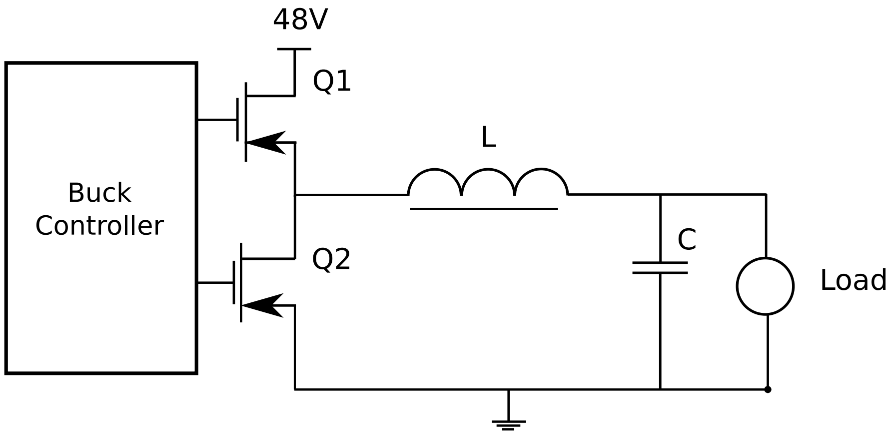


**Figure A.2** Synchronous Buck Converter.

To get around these problems a Synchronous Rectification converter, see Figure: A.2, was designed on an external board for testing. This type of converter use a MOSFET instead of the diode as the lower switch. The advantages is that the forward voltage drop is replaced with the on-resistance of the MOSFET. For modern MOSFETs this is as low as $3m\Omega$, making the power loss $8^2A * 3m\Omega = 0.192W$. Another advantage with this converter is that it can use nMOSFETs instead of pMOSFETs. Due to the internal design of these the nMOSFETs has lower on-resistance giving less power loss.

The new converter was built as a Halfbridge with a driver IC from International Rectifier, the IRS2183. This IC is controlled directly from the MCU with PWM and uses a current-sensor to make sure the lamp is getting the correct amount of current for the brilliancy level selected. As the load from the light can be approximated as constant, the current feedback is not necessary but it can compensate for possible age degradation of the light bulb and is used to make sure the lamp is not broken.

# B

# SAGA Light Measurements

As the light parameters is one of the most important parts of the saga this was measured thoroughly, described more in Section 4.2. Because the mechanics is the same in the new saga the only parameter that can change is the luminosity. To be able to verify this parameter measurements were taken of the original product and compared to the new design.

The measurements were done with a luxmeter in a darkroom at a fixed distance from the unit. As the luminosity is not constant in the whole light-beam the maximum values were used.

| Brilliancy | Old unit | New design |
|---|---|---|
| Low | 2140 | 2150 |
| Medium | 7100 | 7150 |
| High | 21000 | 20500 |

**Table B.1** Comparison between the old unit and the new unit

Exact values are hard to get but as the small difference seen in table B.1 is small enough to confirm that the luminosity is the same. As stated in the specifications the different brilliancy levels should be 100%, 30% and 10%. This is confirmed to be correct by the measurements made.

# C

# LED vs Halogen

Evaluation of Halogen vs LED
and the use in SAGA

Joakim Arnsby, Mårten Kjellsson





SAFEGATE
GROUP

# 1 Purpose

This paper is written to explain halogen lights and Light Emitting Diodes as well as making a quick general comparison of both. To help the decision making in the SAGA [1] application a dedicated comparison for this case is included in the conclusion section.

# 2 Halogen

The Halogen light is based on incandescent light bulbs, it uses a filament which is heated by a current to produce the emitted light. In a Halogen light bulb tungsten is used as the filament. When the filament is heated up the tungsten evaporates and hits the cooler wall where it condenses and the glass gets darker.

To prevent darkening of the glass small amounts of halogens, iodine or bromine, has been added to the filling glas inside the bulb. This triggers what is called “The halogen cycle”. The tungsten and the halogens combine into molecules that do not stick to the inner walls of the glass. Due to thermal convection the molecules in gas form move around inside the bulb. When they move close enough to the hot filament they break up again into tungsten and halogen.

After breaking up the tungsten is deposited onto the cooler part of the filament, for example the legs, and the halogens are free to combine with the tungsten vapor again. This cycle keeps the inner walls clear throughout the whole lifetime of the bulb and enables smaller bulb sizes than original incandescent lights [9].

One of the main reasons for the Halogen lights not being energy efficient is that the filling gas inside the bulb conducts the heat away from the filament, thus requiring more energy to be added to the process in order to remain at the same intensity. To prevent this the filling gas can be exchanged for something less conductive. This is for example done in Xenon type lamps whereas the name suggests, the filling gas is xenon. These atoms are larger than for instance argon and therefore conducts less heat. It also slows down the evaporation of the tungsten which increase the bulbs lifetime. The drawback is that xenon gas is rare and expensive [10].

The halogen light is constructed to have peak efficiency at a specific current and voltage. These voltages range from 12V up to 240V. The low voltage models usually have longer lifetime as the filament is much shorter and thicker to be able to handle the higher current. If the light runs on a higher than specified voltage the light emitted is increased but as little as five percent over voltage reduces the service life by 40$\%$. If it is run at a lower current and voltage, for example being dimmed, the efficiency is reduced. The decreased operating power can also interfere with the

“Halogen cycle” and result in the blackening of the glass, thus reducing the light emitted considerably. Therefore if a halogen light is constantly dimmed there will not be much energy saved and it is better to change it to another model [11].

## 3 LED

The basic physics that describes the emission of light in a LED relies on the principle of a p-n junction where current can flow from the anode to the cathode but not the other way around. In this p-n junction the p-side is full of so called holes and the n-side has an overdose of electrons. As an electron is transferred from the n-side to the p-side it hits a hole in the p-side and there it jumps to a lower electron layer [2].

The materials used in the p-n junction affects what wavelength the emitted light has, as different materials emit different amounts of energy when electrons jump to lower layers. This means that the colour of LEDs are limited to what energy levels the electrons in the material emits when exited and the cost of the different materials.

A big problem in the LED community have been to make a LED with a colour profile that matches current incandescent lights as it is a warm white light and white light consists of a mix of different colours. Because of this quite a few different materials have to be mixed in the LED to be able to emit a light that will appear white to the human eye. This was first achieved by Dr Shuji Nakamura with the University of California in Santa Barbara and the discovery was so important he was awarded the Millennium Technology Prize [3].

Because white LEDs actually are different materials mixed, it needs more power to be able to emit white light with the same intensity as an ordinary blue LED. As a result white LEDs are often created from blue LEDs with a yellow sulphur coating as a filter to emit as white light as possible [6]. A LED without coating emits light in a very narrow line perpendicular to the silicon surface. In most uses of a LED it is not suitable with a light that only emits with a small dispersion. Because of this most LEDs are coated with a layer that spreads the light to predefined dispersion angles [4].

## 4 Conclusion - Halogen vs LED

When comparing the two technologies there are not many things that points to the halogen lights favour. Main issues are that they are less energy efficient and have shorter lifetime. The advantage of the halogen light is that it does not require any cooling and can run directly from mains power without any expensive and complicated driver, and it is cheaper per unit.

In early LEDs there were problems with getting the right light temperature. It was too cold to be able to replace the incandescent lights. But in the past few years there has been a lot of effort put in to make the white LEDs warmer and more incandescent like.

The luminous intensity of the different light sources can be equivalent, with the major difference to the LEDs advantage that the halogen light consumes at least five times the energy to emit light with the same intensity [5].

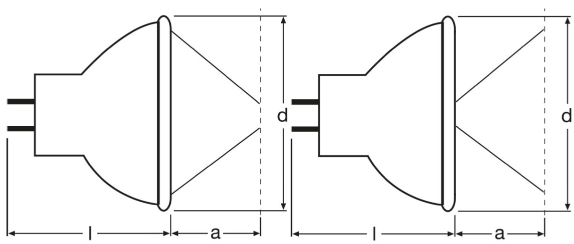


Figure 1: The beam profile of the halogen light [12] in SAGA on the left, beam of a general LED to the right.

## 4.1 SAGA

Substitution of the current halogen lights in the SAGA units are possible but will require some mechanical modifications since the light emitted from a LED does not have the exact same properties as the halogen light.

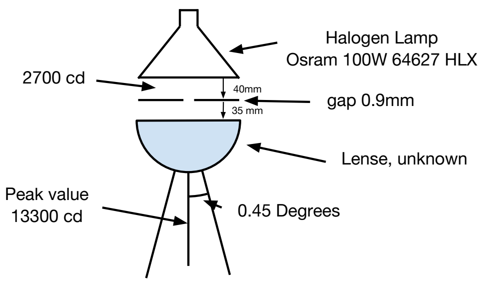


Figure 2: The lamp and lens configuration on SAGA

The halogen light in the current SAGA implementation has its focus point a=40mm, see Figure 1. The beam passes through a rectangular gap to shape the output and then through a lens to focus the beam, see Figure 2. The result is a rectangular shaped beam with a 4.5° view angle. This setup is optimized to use as much light as possible from a predefined light source [12], but will probably work with any light source with focus point at 40mm. The general LED does not have the same focusing effect as this specific halogen light, see Figure 1, wich makes it impossible to directly change to a LED without a focusing lens.

The main advantage of a substitution to LED is the reduced power consumption, thus requiring a smaller and cheaper powerstage than in the existing product. As the LED can be quickly turned on and of the mechanical shutter, today constructed with a gear and cover plate can be removed as well.

One reason as to why not to substitute the existing halogen light to LED is that it makes it more difficult to ensure backward compatibility. It is in no sense impossible, but requires consideration during the design of the electronics for the SAGA.

To conclude; though it is possible to find an equally intensive LED the optical path will have to be modified to achieve the same focusing properties as with the halogen light. Exactly how this should be done is not covered by this paper and needs to be investigated further.

## References


[1] http://www.safegate.com/tibet/template/media%2CMediaObjectFile.vm?siteid=1040&objectid=2521&size=large

[2] Floyd,ThomasL.,ElectronicDevices3rdEd.,Merrill,1992

[3] http://www.ia.ucsb.edu/pa/display.aspx?pkey=1475

[4] Bela G. Liptak, Béla G. Lipták Instrument Engineers' Handbook: Process control and optimization, CRC Press, 2005, ISBN 0-8493-1081-4

[5] http://www.osram.com/osram_com/trends-and-knowledge/led-home/professional-knowledge/led-basics/index.jsp

[6] http://www.osram.com/osram_com/trends-and-knowledge/led-home/professional-knowledge/led-basics/light-colors/index.jsp

[7] http://www.osram.com/osram_com/trends-and-knowledge/led-home/professional-knowledge/led-basics/basic-knowledge/index.jsp

[8] http://www.osram.com/osram_com/trends-and-knowledge/halogen-lamps/professional-knowledge/index.jsp

[9] http://www.osram.com/osram_com/trends-and-knowledge/halogen-lamps/professional-knowledge/halogen-cycle/index.jsp

[10] http://www.osram.com/osram_com/trends-and-knowledge/halogen-lamps/professional-knowledge/halogen-eco-technology/index.jsp

[11] http://www.osram.com/osram_com/trends-and-knowledge/halogen-lamps/professional-knowledge/optimum-operating-voltage/index.jsp

[12] http://www.osram.com/appsinfo/pdc/pdf.do?cid=GPS01_1028532&mpid=ZMP_56079&vid=EU_ALL_eCat&lid=EN