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**WIRELESS HOME AUTOMATION  
LIGHTING CONTROLLER**  
Master's Thesis

Author applying for  
master's sciences of technical  
academic degrees

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**AUTHOR'S DECLARATION**

I hereby declare that this thesis is the result of my independent work.  
On the basis of materials not previously applied for an academic degree.  
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# TABLE OF CONTENTS

<b>Confidentiality requirements .....</b>	<b>6</b>
<b>Foreword .....</b>	<b>7</b>
<b>List of abbreviations.....</b>	<b>8</b>
<b>1. INTRODUCTION.....</b>	<b>9</b>
<b>2. DESIGN OF THE CONTROLLER.....</b>	<b>13</b>
2.1 Wireless communication .....	13
2.2 General requirements.....	14
2.3 CE marking and European directives .....	15
2.4 Circuit design.....	18
2.4.1 Power .....	18
2.4.2 Protection components.....	20
2.4.3 Bluetooth module.....	21
2.4.4 1 V - 10 V outputs.....	23
2.4.5 AC switching .....	26
2.4.6 Memory.....	28
2.4.7 Antenna matching network.....	29
2.5 PCB Design .....	30
2.5.1 Mains input design.....	31
2.5.2 Crystal oscillator design considerations.....	32
2.5.3 Voltage regulator thermal improvement.....	33
2.4.4 Trace antenna design.....	33
2.6 Programming .....	34
<b>3. TESTS, MEASUREMENTS AND IMPROVEMENTS.....</b>	<b>37</b>
3.1 Power factor.....	37
3.1.1 Power and power factor measurements .....	39

3.1.2 Harmonics measurements .....	42
3.2 Input voltage measurements .....	43
3.3 Bluetooth range assessment.....	44
3.4 1 V - 10 V output measurements .....	45
<b>4. PRODUCTION COST.....</b>	<b>48</b>
<b>5. CONCLUSIONS.....</b>	<b>51</b>
<b>6. KOKKUVÕTE .....</b>	<b>54</b>
<b>REFERENCES.....</b>	<b>57</b>
<b>APPENDIX A Example of EC Declaration of Conformity .....</b>	<b>61</b>
<b>APPENDIX B Photos of the prototype.....</b>	<b>62</b>

## **Confidentiality requirements**

This thesis is only for applying for degree of Master of Technical Sciences. Reproduction and use of thesis content is forbidden without the prior permission of the relevant author.

## **Foreword**

The topic for this thesis was given by the company THE Systems LLC where most of the design and research work was also done. I would like to thank the team working there for all of the support and help they provided.

## List of abbreviations

LED – light-emitting diode

RMS – root mean square

DALI – Digital Addressable Lighting Interface

PCB – printed circuit board

PWM – pulse-width modulation

DAC – digital-to-analog converter

ADC – analog-to-digital converter

SOC – system on chip

AC – alternating current

DC – direct current

SMPS – switched-mode power supply

OTA – over-the-air programming

OTP – one-time programmable

JTAG – Joint Test Action Group

SWD – Serial Wire Debug



# 1. INTRODUCTION

The topic for this thesis has risen from the growing demand and popularity of smart appliances and home automation. This trend of interconnected and increasingly smarter devices has been summed up in the popular term Internet of Things. It is the new catchphrase of embedded systems design and it was even the main focus of 2015 conference Embedded World, which is one of the biggest conferences on the subject of embedded technologies [1].

With the increased awareness of environmental concerns and the need for higher energy efficiency, LED-s are becoming more and more popular for home and commercial lighting. This has led to a problem of controlling these lights, particularly in dimming. Traditional incandescent lights are dimmed by devices that cut the voltage waveform (Figure 1.1), reducing the RMS current and therefore dimming the light.

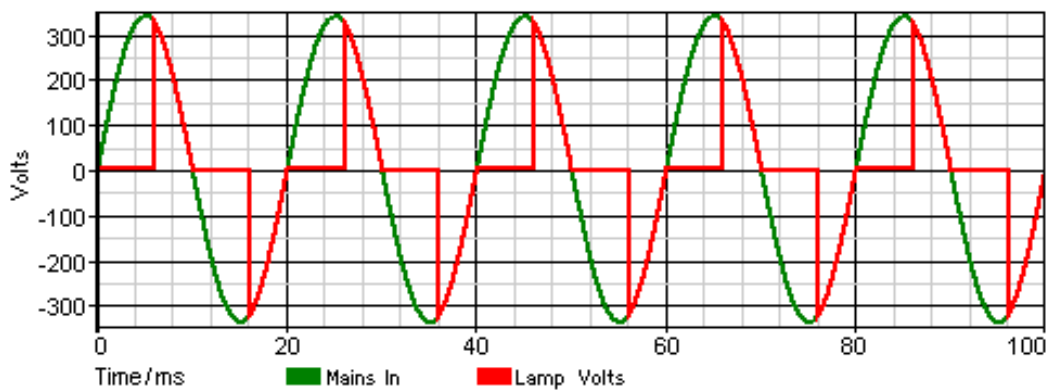


Figure 1.1. Illustration on how triac dimmers change the voltage waveform

This is a problem for LED lights because, unlike incandescent lights, they do not present a linear load to the dimmer and they draw current that is almost an order of magnitude lower. Conventional dimmers that are meant for incandescent lights use triacs which require minimal operating current to perform properly. LED lights generally do not meet this requirement, which can make them flicker or completely non dimmable. This can be addressed by making dimmable LED lights, which have additional circuitry that draw more current just to keep the dimmers working properly. This adds cost to manufacturing these lights and because the extra energy it uses is simply wasted as heat, it makes the lights less efficient. There are also special LED dimmers that are usually more expensive and that might only work with specific lights, since LED lights can differ from manufacturer to manufacturer.

Another option that is increasing in popularity is using special LED drivers to power these lights. These drivers come in a variety of options, including constant voltage or constant current output, different dimming inputs and integrated protection features, like overheating, overload and short-circuit protection [2].



Figure 1.2. Osram 24 V constant voltage LED driver with 1 V - 10 V input

Two of the most widespread dimming alternatives for these LED drivers are 1 V - 10 V input and DALI interface. 1 V - 10 V input dimming is very simple and can even be used with a plain potentiometer connected between the dimmer inputs. 1 V represents about 10 % light brightness and 10 V is 100 % brightness. The drawback of this technique is that it cannot turn the light completely off from the dimming input, so there needs to be a separate switch for that. Also, one controller or channel can only control one light or a group of lights. If a more complicated system is needed, then more controllers or channels are needed and each group or light needs separate connections. DALI interface is more suitable for complex solutions, because one controller can operate up to 64 drivers that can be connected in parallel or in series, simplifying wiring greatly [3]. Downside is the difficulty of implementing it. Furthermore, it requires voltages up to 22.5 V, which complicates the hardware design.

The intended purpose for this device is primarily for residential lighting control, where the complexity is usually low. For this reason and because 1 V - 10 V is a simpler interface to start with, it was decided that initially the device is going to use this interface. From hardware standpoint it should not be too difficult to make a DALI version in the future, only the voltage regulation circuit needs to be changed to allow for higher voltages.

The goal for this work is to design a device that can control these power supplies using the 1 V - 10 V input. It needs to be as small as possible and use very little power. It also must be wirelessly controllable and able to control multiple lights at the same time. Since the company that offered this subject deals mostly with lighting controllers and Bluetooth controlled devices, this device was a natural progression in its development line.

Multiple options are already on the market for wirelessly controllable LED lights. There are light bulbs that have Bluetooth capability built-in that are meant to be retrofitted into E27 sockets (Figure 1.3).



Figure 1.3. Ilumi A21 Smartbulb

These are generally more expensive than regular LED lights and only work with lighting solutions that merely use bulb lights. Modern lighting solutions use a variety of different lights, including bulbs, LED strips and other kind of lights.

Most manufactures that make these LED drivers also offer some kind of dimmers for them. The simplest ones are just regular wall mounted rotary dimmers similar to regular triac dimmers, but that are compatible with 1 V - 10 V or DALI interface. More advanced dimmers include remote controls for wireless control or wall mounted touch panels. There are also Bluetooth dimmers that can be managed through a smart phone application. The company that offered this topic also produces a range of lighting controllers that are operated by an application on a smart phone using Bluetooth. Much like most of the Bluetooth dimmers on the market, these are meant for controlling the LED-s directly and are intended for a more specific purpose. The idea of the planned device would be to offer a simple and inexpensive, yet highly adaptable alternative to the existing selection. Because it controls the lighting

drivers, it does not matter what kind of lights are used or how powerful they are, as long as the proper driver is used. This gives it a high level of flexibility.

This work is roughly divided into two parts – the research and design part and the measurement and analysis part. In the first portion, different options for solving main design questions are explored and explained. Also, in that part key requirements for the device are set and legal aspects of getting a product on the market are researched. It starts with circuit design, where the selection of components and methods are described. After that comes the PCB design part. In that segment significant aspects and techniques of the PCB design are covered. Both circuit and PCB design were done with an electronic design automation software PADS from Mentor Graphics. In the latter portion, tests and measurements that were made with the prototype are looked at and analyzed. Based on the results of these measurements, improvements are made to the initial design. The scope of the work mainly includes the hardware design, leaving out the software and casing design. However, since software and hardware are related to each other, some aspects of programming and software are briefly covered.

## 2. DESIGN OF THE CONTROLLER

### 2.1 Wireless communication

Bluetooth Low Energy is a subset of Bluetooth 4.0, also known as Bluetooth Smart. It operates around 2.4 GHz in the ISM band, which is license-free [4]. The low energy part is what makes it stand out compared to older versions of Bluetooth. It uses significantly less energy than the previous version while active and while on stand-by [4]. It is compatible with the newest Android, Windows, Apple OS X and iOS devices [5].

Because of these reasons and because the company already had some experience with Bluetooth devices, it was decided to use Bluetooth Low Energy for wireless communication. It allows communication between multiple peripheral devices with one central device (Figure 2.1), but peripheral devices cannot communicate with each other. For this application, it means that multiple devices can be controller simultaneously by one smartphone for instance. But the devices cannot communicate with each other or any other peripheral device, like motion sensors for example. To accommodate this, an extra device would be needed that handles all of the communications between different peripheral devices.

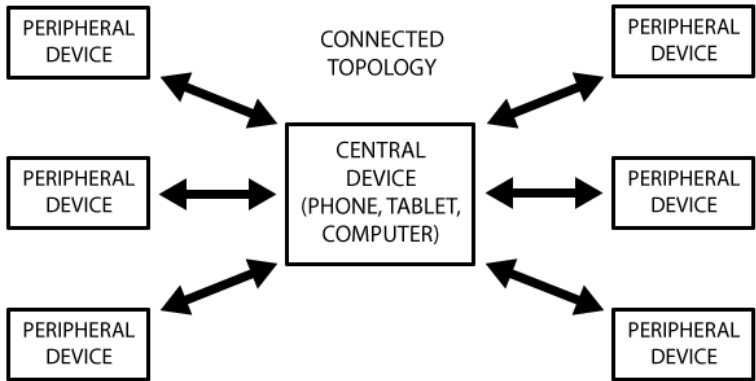


Figure 2.1. Bluetooth Low Energy connections

Bluetooth Low Energy protocol uses concepts called services and characteristics. Characteristics represent the basic data that is related to a single variable or measurement, while services contain characteristics that form a logical unit. Both services and characteristics have their own 16 bit or 128 bit unique numeric ID. For example, in this device there could be a service for output control, which holds a characteristic for each output channel where the output value is stored. Another service might be system information that

holds characteristics for a serial number and manufacturing information. Connected central device can then read or write these characteristics. It can be made so that users can only access services that are made available to them, while the manufacturer has access to all of the services.

## 2.2 General requirements

At the beginning of development some key requirements were decided. Firstly the physical size of the device was determined. It was agreed that it should be made to fit inside a standard electrical mounting box (Figure 2.2). This allows for easy installation during construction or to be retrofitted in place of an existing switch or power outlet.



Figure 2.2. Electrical mounting box

Second requirement was that it needed to be powered directly from mains electricity without needing any extra power sources. Also, to keep in line with the high efficiency of LED lights and their drivers, the device itself needed to have low energy consumption.

Finally, the device should be as simple as possible and inexpensive to manufacture. This means using surface mount components only or at least as many as possible. Also, if there is enough space on the PCB then all of the components should be on the same side of the PCB. Having components on both sides means the PCB needs to go through the process of component placement and soldering twice, increasing production time and cost. Through-hole components on a board that is mostly surface mount means that they generally need to be hand mounted and soldered, further increasing the production cost.

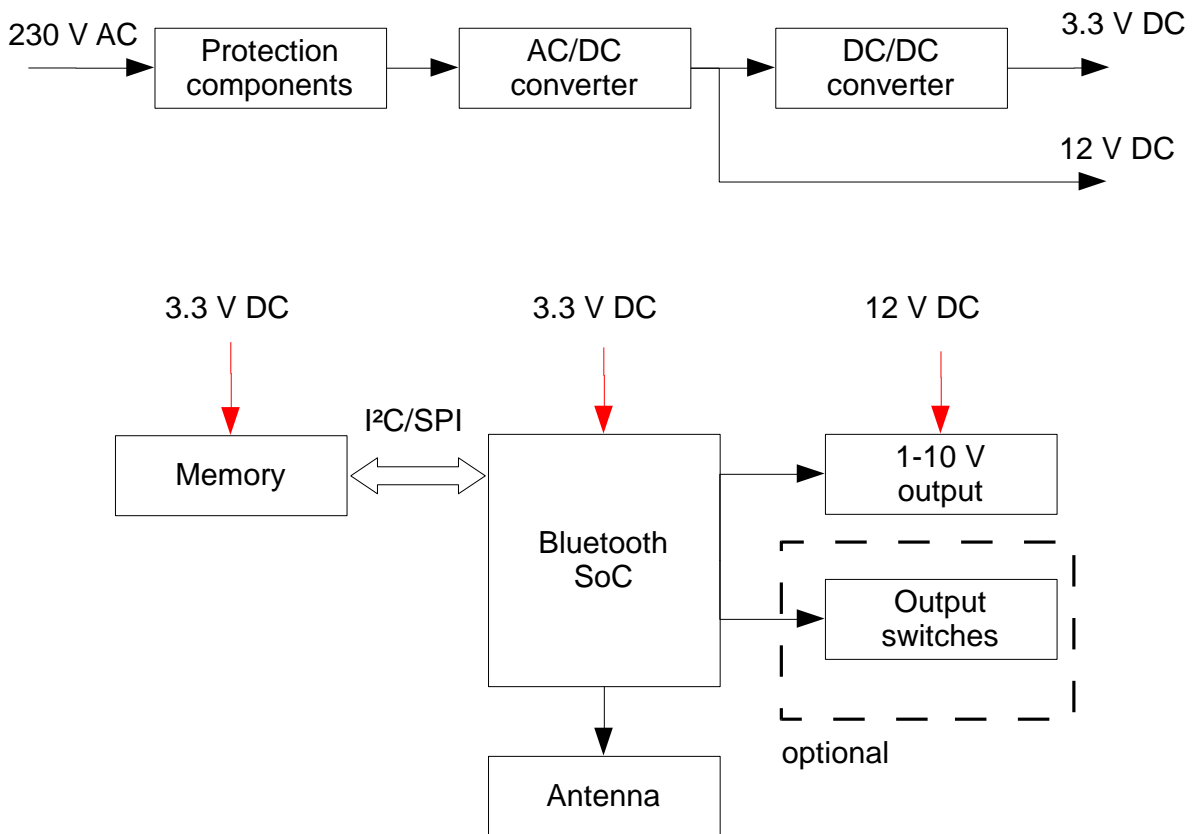


Figure 2.3. Block diagram of the planned device

The goal was to make the device compliant with the following standards:

- EN 61347-1 General and safety requirements for lamp controlgear
- EN 61347-2-13 Particular safety requirements for DC or AC supplied electronic controlgear for LED modules
- EN 62384 Performance requirements for electronic controlgear for LED modules
- EN 61000-3-2 Electromagnetic compatibility – limits for harmonic current emissions
- EN 61000-3-3 Electromagnetic compatibility – limits for voltage changes and flicker
- EN 61547 Electromagnetic immunity requirements
- EN 55015 Limits of radio disturbance

## 2.3 CE marking and European directives

CE mark declares products conformity to all applicable European directives. It is mandatory for all products that fall into the scope of any of these directives in order for them to be sold in the European Economic Area. These directives do not offer any technical details or

requirements. Technical information is provided by European harmonized standards. Meeting these standards can ensure conformity with the appropriate directives. CE marking relates only to safety, health and environmental protection and it does not guarantee quality or anything else. Ensuring the conformity with these directives and standards is the manufacturer's sole responsibility. Primarily, applying CE marking to a product is done by manufacturer's self-certification. Apart from few specific product classes like medical devices or some machinery, no third party certification is required. CE mark has exact shape and proportions (Figure 2.4) and it needs to be applied to the product or packaging visibly and legibly.

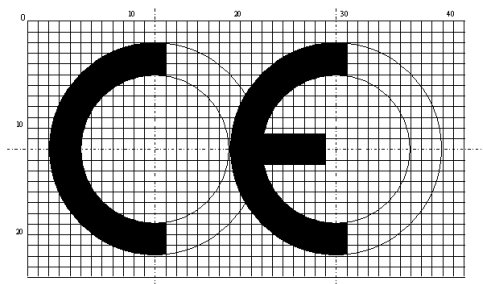


Figure 2.4. CE marking proportions

To declare conformity with the relevant directives, the manufacturer needs to add the CE marking on the product and present two documentations - technical documentation [6] and declaration of conformity [7].

Technical documentation, also known as the technical file, must include all of the relevant information regarding the design and manufacture of the product. Few examples of what a technical file may consist of:

- General description and photos of the product
- Technical drawings and diagrams
- Bill of materials
- Instructions
- Reports and assessments
- List of applied standards
- Declaration of conformity

Technical file must be made available on request by the proper authorities up to 10 years after the end of production for the particular product.



Declaration of conformity is the legal document that declares that the product complies with the mentioned directives. It has to be signed by a person who can be held accountable for the compliance with these directives. A declaration of conformity must include:

- Manufacturers information
- Model and/or serial number of the product
- List of relevant directives
- List of applied standards
- Name and position of the person signing the document
- Signature
- Date

For this device, two directives apply – the Low Voltage Directive 2006/95/EC [8] and the Electromagnetic Compatibility directive 2004/108/EC [9].

The Low Voltage Directive applies to any device that consumes or generates electricity in the range of 50 V to 1000 V for AC and 75 V to 1500 V for DC. The essential requirement set by this directive is that the product shall not endanger people, property or domestic animals when properly installed and used in applications for which it was designed for. It does not specify how to measure the safety of the product or even define what safety means. To get more technical details, harmonized standards need to be considered. By complying with appropriate standards, confidence can be gained that the product conforms to the directive. In case of the planned device and the Low Voltage Directive, harmonized standards EN 61347-1 and EN 61347-2-13 can be employed for example.

The electromagnetic compatibility directive applies to almost all electrical products, except for components and some products that are covered by more specific directives. The principal requirement of this directive is that the product must not emit unwanted electromagnetic interference. Also, that the product must be able to operate normally while subjected to a reasonable amount of interference. For this device, appropriate harmonized standards to demonstrate compliance with this directive are EN 61000-3-2, EN 61000-3-3, EN 61547 and EN 55015.

It is necessary for this device to receive the CE marking and therefore comply with the previously mentioned standards. However, the testing and assessment has to be done when the product is finalized. When it is ready then the technical documentation and declaration of

conformity must be produced. This work focuses mainly on the design part and the production of the first prototypes. The actual assessments and the production of the technical file and declaration of conformity are not within the scope of this work. Still, the key requirements of both directives were kept in mind while designing the product.

## **2.4 Circuit design**

### **2.4.1 Power**

First problem that needed to be solved was how to power this device directly from mains electricity. The biggest challenge is how to step down the voltage from 230 V to the range of 12 V. There are few well-known methods for this.

The most common is by using transformers. Transformers are simple to use and they offer galvanic isolation. The downside of transformers is that they are rather big compared to other components and they can be inefficient. This due to their no load losses, which can be around 1 W for small transformers in the range of 0.35 VA to 0.5 VA output power [10]. For a device that uses very little power itself, this can be more than half of the total power consumption.

Another solution would be to use a capacitor to drop the voltage down to desirable levels. Applications using this method are known as capacitive drop power supplies. It uses the reactance of a series connected capacitor to limit the voltage and current, much like a regular resistor performs in a DC circuit. The advantage of using a capacitor instead of a resistor is that since reactance is the imaginary component of impedance, it does not produce any real work and therefore does not waste energy [11]. The downside of this method is that it provides no isolation between the device and mains power. Also, proper capacitors rated for this kinds of applications are harder to find and more expensive than regular capacitors.

The easiest solution would be to use an external SMPS. This would be a good option, as these kinds of power supplies are very efficient and easy to use. However, it was decided at the beginning that this device cannot use any external equipment, as this would complicate installation. It is also possible to build a SMPS into the device, but this is very complicated and requires a lot of components and space.

Method	Size	Cost	Complexity	Isolation	Efficiency
Transformer	medium	low	low	yes	low
Capacitive drop	small	low	medium	no	high
External SMPS	very big	high	low	yes	high
Internal SMPS	big	medium	very high	yes	high

Table 2.1. Power solutions comparison

Looking at Table 2.1 it would seem that capacitive drop method would be a good option, if it were not for the lack of isolation. Having no galvanic isolation is more dangerous and it may lead to some compatibility issues with some LED drivers, because it is not always specified whether the 1 V - 10 V inputs are isolated. The next best option would be using a transformer. It has the lowest efficiency of them all, but because the power consumption of the device is low, it should not be that big of a problem.

After the voltage has been lower to the desired level, then it is just a matter of rectifying it with a diode bridge and controlling it with a voltage regulator (Figure 2.5).

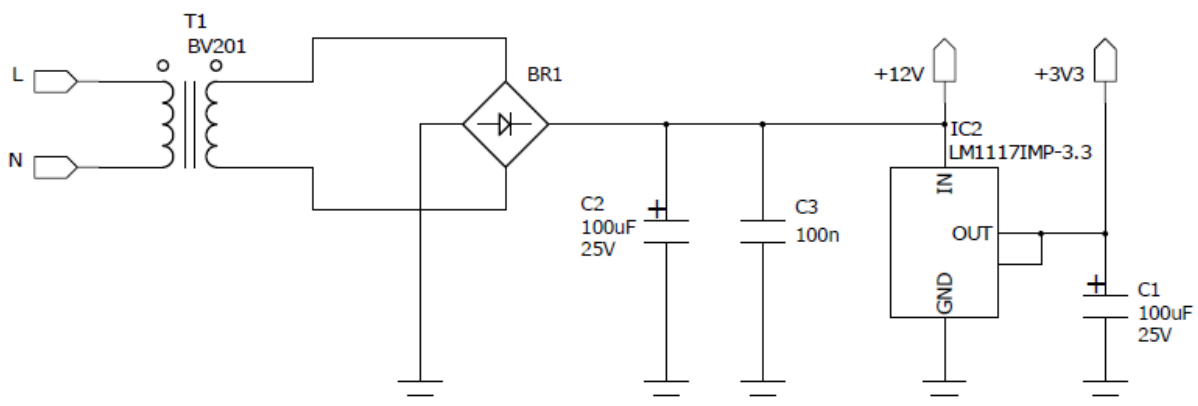


Figure 2.5. Voltage regulation

The transformer has been selected so that after the diode bridge and capacitors, the voltage is around 12 V, which can be used to power the amplifiers for the 1 V - 10 V output. Smallest transformers that are readily available are with a power rating of 0.35 VA, which is enough for this device. Secondary voltage of the transformer was selected to be 9 V because the device draws so little current that the transformer operates near its no-load voltage, which is higher than its rated secondary voltage [10]. Based on these, a BV 201 0136 transformer from HAHN was used (Figure 2.6). For everything else the voltage is further lowered to 3,3 V and stabilized with a fixed output voltage regulator.



Figure 2.6. BV 201 0136 transformer from HAHN

## 2.4.2 Protection components

To protect the device from a voltage surge or over current, two safety components were used. These were a variable resistor and a fuse (Figure 2.7). A variable resistor is a resistor which resistance depends on the voltage. In normal operation the resistance is very high and it does not affect the device in any meaningful way. During a voltage surge the resistance drops drastically and provides a low impedance path for the extra current before it can reach the protected device. To protect components on the device from excessive current in the event of a short circuit or an overload, a fast acting fuse was added. This approach does not guarantee full protection of the device, but it should be acceptable for this application.

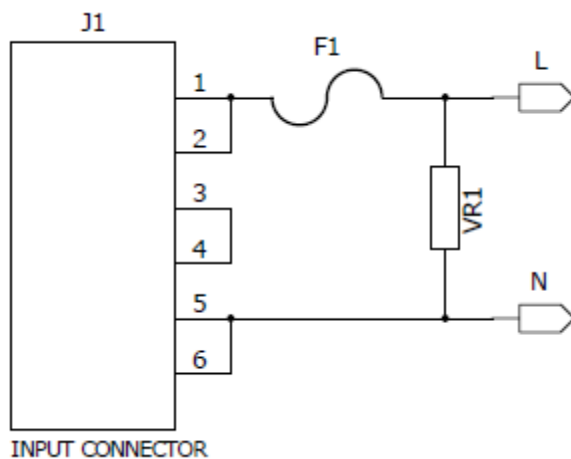


Figure 2.7. Input connector and protection components

For connecting mains electricity wires to the device, a vertical connector with push-button mechanism was used. Vertical direction of connection allows for easy insertion of the wires without having to bend them. Also, a vertical connector takes less room on the PCB than a horizontal or an angled one. Push-button release mechanism makes it easy to install. No tool is needed to insert wires and for removal a small screwdriver or even a pen is enough. For the

first prototypes, a 3-pole connector SR21503VBNC from Metz Connect was chosen (Figure 2.8). The current application does not need 3 inputs, but there might be a need in the future to use the protective earth wire as well to ground a metal casing or a frame.



Figure 2.8. Metz Connect SR21504VBNC connector

### 2.4.3 Bluetooth module

For selecting the Bluetooth module there were two main options: either to use a module that already has all of the necessary components and an antenna built-in, or to use a chip that required external components and an antenna. Using a module has the benefit of requiring less design work, but they are more expensive. Design is a one-time cost, so using less expensive chips reduces the production cost of the device. Based on this it was decided that the device was going to use a Bluetooth chip.

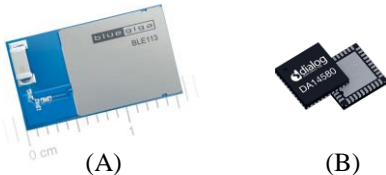


Figure 2.9. Bluegiga BLE113 module (A) and Dialog Semiconductor DA14580 SOC (B) size comparison

Since the company already had development kits for a relatively new DA14580 low power Bluetooth SOC from Dialog Semiconductor, it was agreed to use this. It is compliant with Bluetooth 4.1 standard, it has a variety of integrated functionality (Figure 2.10) and it comes in a small QFN40 package that is only 5 mm by 5 mm [12].

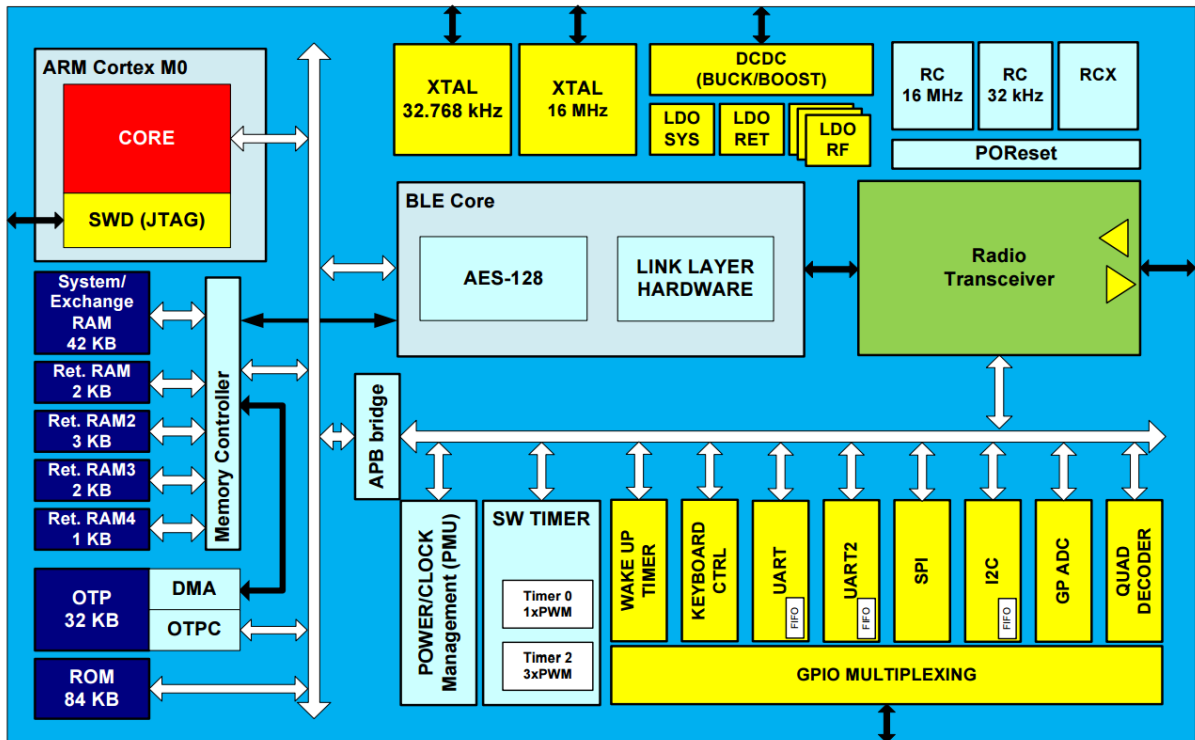


Figure 2.10. DA14580 block diagram

Key features of the DA14580:

- 16 MHz 32 bit ARM Cortex-M0 processor
- 32 kB One-Time-Programmable memory
- 4 PWM channels
- 4 10 bit Analog-to-Digital converter channels
- Supply voltage 0.9 V – 3.6 V
- 0 dBm transmit output power
- -93 dBm receiver sensitivity

This chip is mainly intended for wireless applications where it is powered by some sort of a battery. It has internal voltage regulation features and based on what type of a battery is used, different connections and additional components are required. In this device it is powered by a 3,3 V supply, so a configuration that is meant for a 3 V battery is used (Figure 2.11) . This configuration is provided by the chip manufacturer and can handle up to 3,6 V [12].

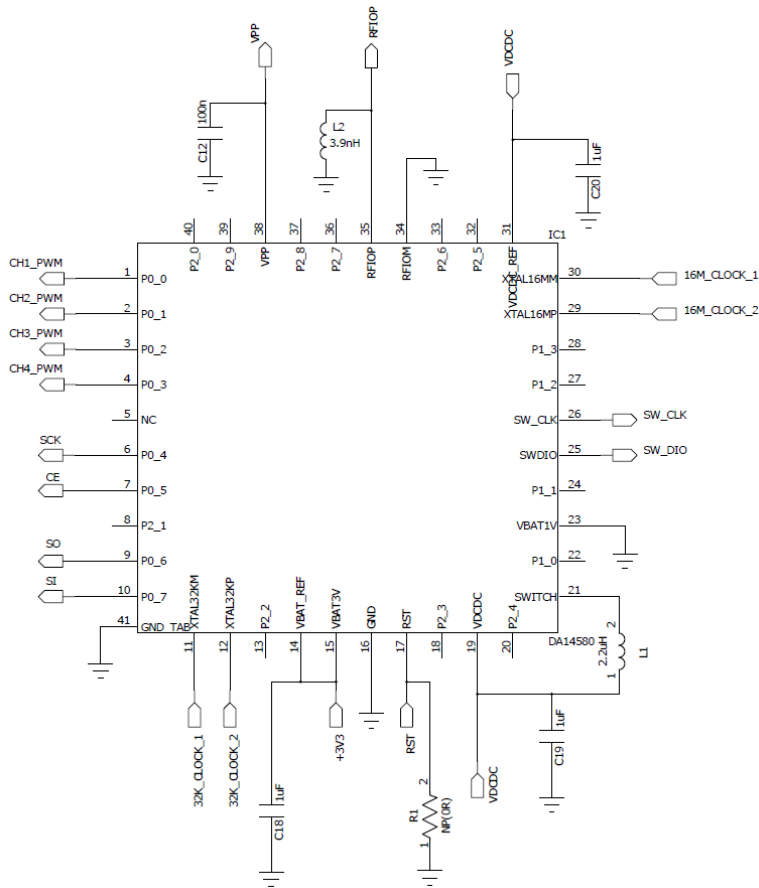


Figure 2.11. Bluetooth chip connections

0 dBm transmitting power is 1 mW, meaning this chip is a power class 3 Bluetooth device [13]. 1 mW output power is generally associated with a range of approximately 1 m, but this depends on a lot of factors and can possibly be as long as 10 m in some situations [14]. This would need to be tested on the prototype as anything below 5 m is insufficient for the intended purpose.

### 2.4.4 1 V - 10 V outputs

The selected SOC does not have any internal DAC-s that could simply output a constant voltage level. It is possible to use external DAC-s, but these add extra cost and take up space on the PCB. Instead, it has PWM outputs that can be used for this purpose. A PWM signal is a square wave signal that goes between ground and the supply voltage of the chip. The ratio of how long the signal is high against the period of the signal determines the average voltage level. This is also known as the duty cycle and is expressed in percentages, where 100 % means the signal is constantly high and 0 % that it is constantly low. With a simple low-pass

filter (Figure 2.12) this square wave can be averaged out to be a constant voltage level, effectively turning the PWM output into a DAC output.

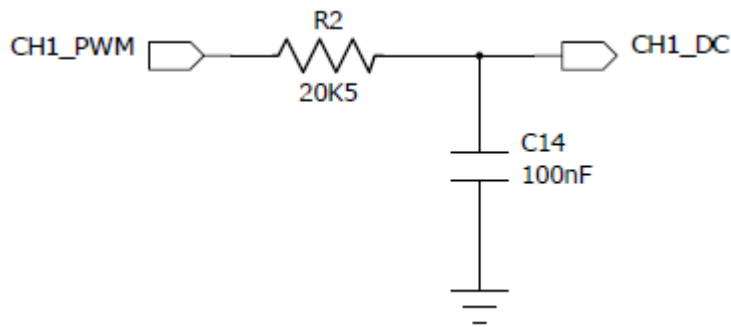


Figure 2.12. Low-pass filter for turning the PWM signal into a voltage level

Selecting the resistor and capacitor values is a trade-off between response time and ripple voltage. The faster the response time the higher the ripple voltage and the other way around. Neither are a critical issue for the current design, as a ripple of 0,1 V would mean light brightness variation of just about 1 % with frequency of 8 kHz. Even if the LED drivers would detect this, it would be completely invisible for the human eye [15]. Response time below 50 ms is probably enough for it to feel instant. To keep the number of different components down and manufacturing as simple as possible, first resistors and capacitors that were already used somewhere in the design were considered. Using an online simulation tool [16], resistor value of 20,5 k $\Omega$  and capacitor value of 100 nF were selected out of the already used components. According to the online simulation tool, this combination gave a peak-to-peak ripple voltage of 0,05 V and response time of about 5 ms, which is more than enough for this application.

Since the chip can only output voltages up to its own supply voltage, even with 100 % duty cycle the voltage will only go up to 3,3 V. This means in order to get 10 V at the output, the signal from the chip needs to be amplified. For this purpose a simple non-inverting amplifier made with a general purpose operational amplifier was used (Figure 2.13). Since these kinds of operational amplifiers are very common and this application does not present any critical requirements, the selection was made based on price and availability. LM358DRG3 general purpose operational amplifier from Texas Instruments was chosen.



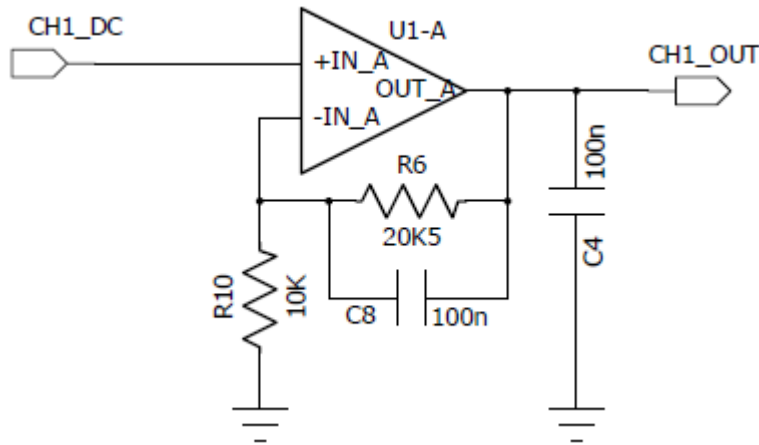


Figure 2.13. Non-inverting amplifier

The amplification is determined by the two feedback resistors. Since these resistors form a basic voltage divider between the output and the inverting input, the values can be calculated using this formula [17]:

$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1} \quad (2.1)$$

where  $V_{out}$  - output voltage,

$V_{in}$  - input voltage,

$R_f$  - feedback resistor value between the output and inverting input,

$R_1$  - feedback resistor value between the inverting input and ground.

In this case the desired output voltage is 10 V and the input voltage is 3,3 V. Using formula 2.1 gives us the resistor ratio that is need to amplify the input signal to the required level.

$$\frac{10 \text{ V}}{3,3 \text{ V}} = 1 + \frac{R_f}{R_1} \Rightarrow \frac{R_f}{R_1} = 2,03$$

Close values to a ratio of 2,03 in an E48 series are 100 and 205 [18], which gives a ratio of 2,05. This is close enough for the task at hand, so resistor values of 10 k $\Omega$  and 20,5 k $\Omega$  were selected. Capacitors on the output and feedback are there to stabilize the amplifier.

Connectors for the 1 V - 10 V outputs are regular terminal blocks from Weidmüller (Figure 2.14). Since the wires for the 1 V - 10 V connections are generally smaller and more flexible than mains electricity wires, having a horizontal inputs should not be a problem. However, in

the future these might be changed with the same type of connectors that are used for mains electricity input. This would make the installation possible without needing any tools. For prototypes these terminal blocks were selected based on price and availability.



Figure 2.14. Terminal block PM5.08/3/90 from Weidmüller

### 2.4.5 AC switching

Given that lights cannot be turned on or off with the selected 1 V - 10 V interface, an option to add this feature to the device was considered. Only practical ways to do this is by switching the power for the LED driver or by switching its output (Figure 2.15).

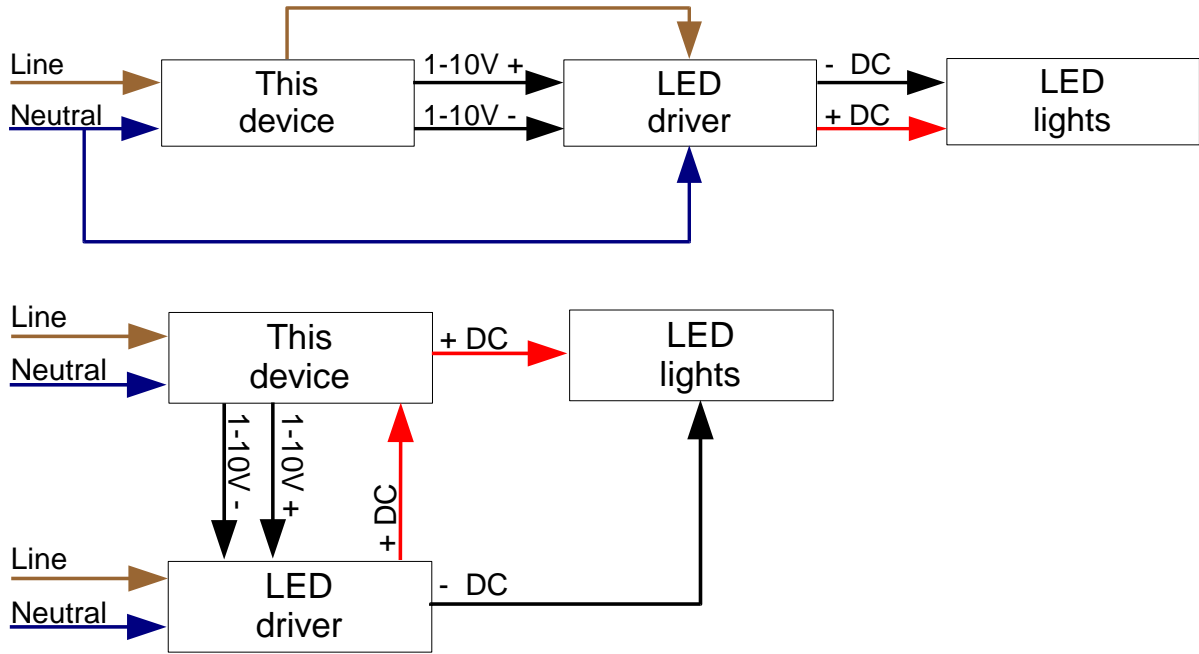


Figure 2.15. Wiring diagram for power switching (top) and output switching (bottom)

The first option requires switching AC, so it can be done by either a relay or a triac. Relays are generally bigger mechanical switches meant for larger loads and triacs are solid state devices meant for smaller loads. Because even a 240 W driver draws only about 1 A [2] and size is important, triacs are a better choice. If the triacs are controlled directly, there may be some issues because of the absence of isolation between the triacs and the main circuit. To avoid this and to improve safety, the triacs should be isolated from the main circuit with triac output opto-isolators (Figure 2.16).

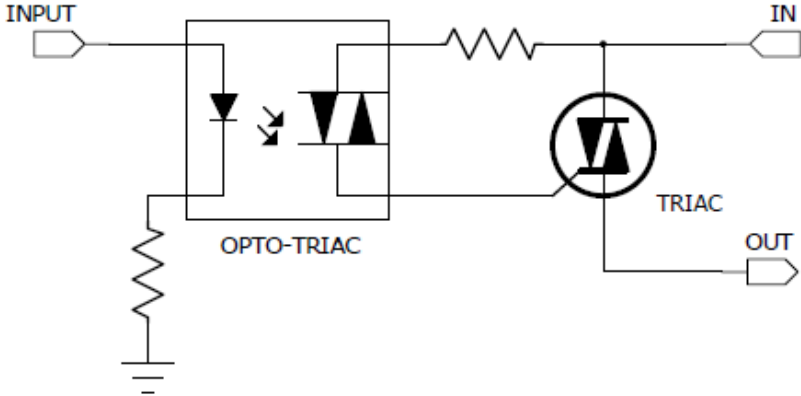


Figure 2.16. Isolated triac switching circuit

The second option seems simpler at first because it requires switching relatively low DC voltages. This can be achieved by using transistors. Minimum component count per output channel is only one transistor, but this may lead to some problems as all of them would need to be referenced to the devices ground. To avoid this and to improve performance of the transistors, a more complicated circuit with opto-isolators and gate drivers would be necessary (Figure 2.17).

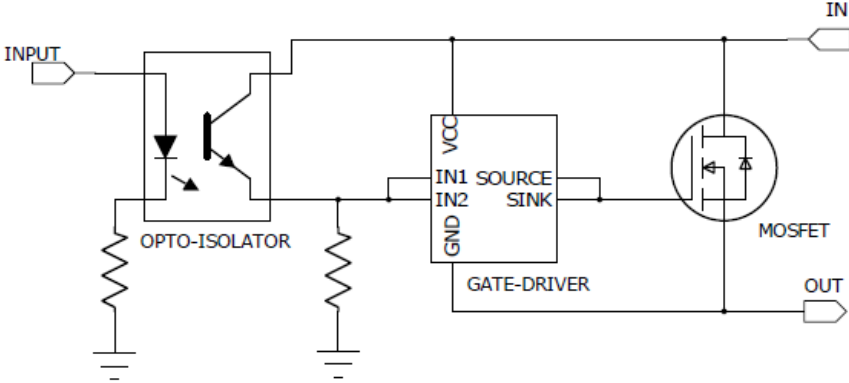


Figure 2.17 Isolated transistor switching circuit

Using this method would have the added benefit of being able to control LED-s that use power supplies that do not have any dimming capabilities. By controlling the transistor with a PWM signal, it is possible to dim the LED by changing the duty cycle of the signal.

Adding either of these options to the device would require more PCB space for extra components and connectors. This means the PCB would need to get bigger or components to be mounted on both sides. It was decided that the first prototypes will not have these features, but if the need arises, they can be added in the future.

### **2.4.6 Memory**

The selected SOC only has OTP memory, which means once it is programmed, no more software updates or fixes can be made. This alone would be acceptable, but it also does not have any non-volatile memory available. This means all user preferences are lost when the device is powered off.

Both of these problems can be solved by adding an external flash memory. A boot loader would be programmed into the OTP memory. This program would then load the main program from the flash memory every time the device is powered on. This way the main program that is stored in the flash memory can be changed, while the boot loader stays the same. The flash can also be used to save user preferences and other variables along with the main program.

For this purpose, a 2 Mbit flash SST25PF020B from Microchip was selected. It communicates over SPI interface that uses 3 lines for data transmission and one for enabling and disabling the chip (Figure 2.18). It also has features for having multiple memories on the same lines or protecting data from being written, but since these are not used, their pins are pulled high.

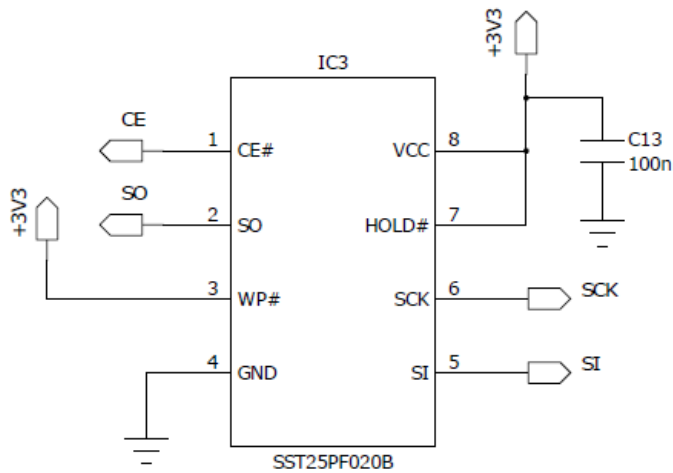


Figure 2.18. Flash memory connections

## 2.4.7 Antenna matching network

To get maximum performance out of an antenna, it needs to be matched to the source [19]. This is due to the maximum power transfer theorem, which states that in order to achieve maximum power dissipation at the load, the load impedance has to match the source impedance [19]. Having an impedance mismatch can also cause signal reflections, which can further lower the performance of the antenna [20]. The part of the circuit that serves the purpose of matching load and source impedances is known as an impedance matching network. There are a few options for this, like using a transformer or some sort of a filter [21]. To allow for greater control over the matching network parameters, a low pass pi filter was selected [21] (Figure 2.19). Also, designing the PCB for a pi filter allows for the use of simpler L filter by not mounting one of the capacitors and switching capacitors and inductors around [22].

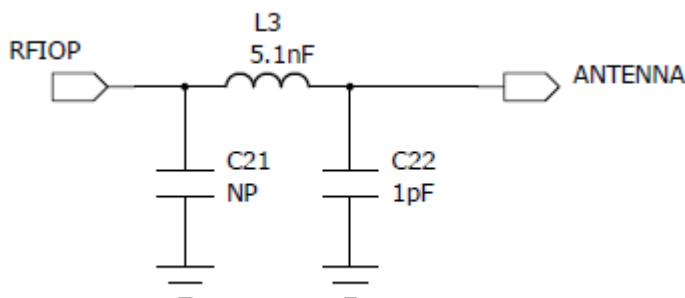


Figure 2.19. PI filter

Even though the antenna design that was finally used should already have an impedance of  $50 \Omega$  and not require additional matching, the matching network was still implemented in the first prototype. The three components it requires are all very small and leaving them in the design allows for testing if any matching is necessary.

### 2.5 PCB Design

It was decided in the beginning that the device should fit inside of an electrical mounting box, so the PCB size and shape was determined. However, round PCB-s are panelized into large rectangular PCB panels anyway [23], so a square frame around the main part of the PCB can be added without increasing waste much (Figure 2.20).

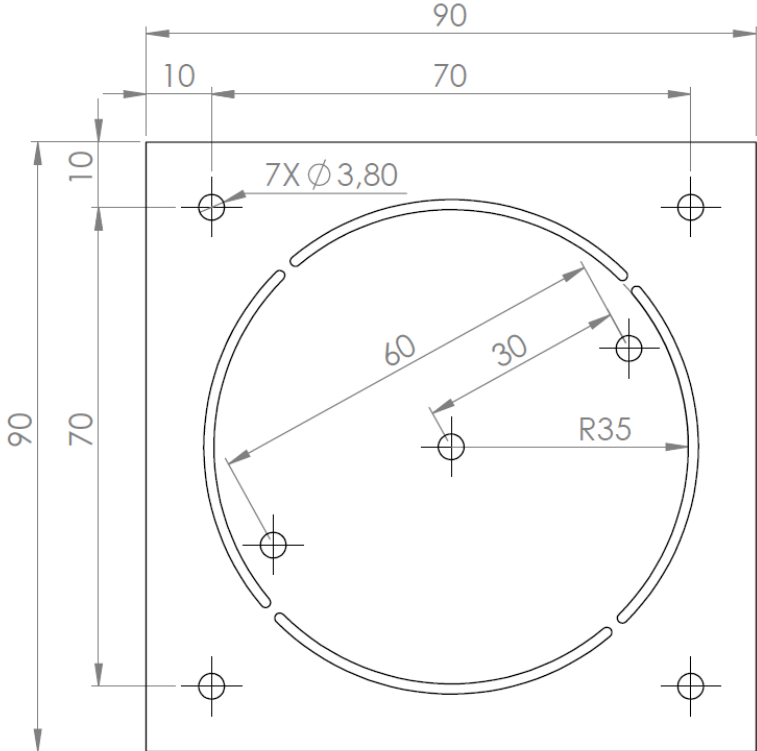


Figure 2.20. PCB size and shape

Cut outs were added around the main part of the PCB for easy removal from the fame. Also, mounting holes were included in the fame so the PCB can be mounted while still inside of the frame.

The PCB itself is made from standard 1,6 mm thick FR4 composite material. It has 35 μm thick copper layers on both sides, with components mounted only on one side (Figure 2.21).

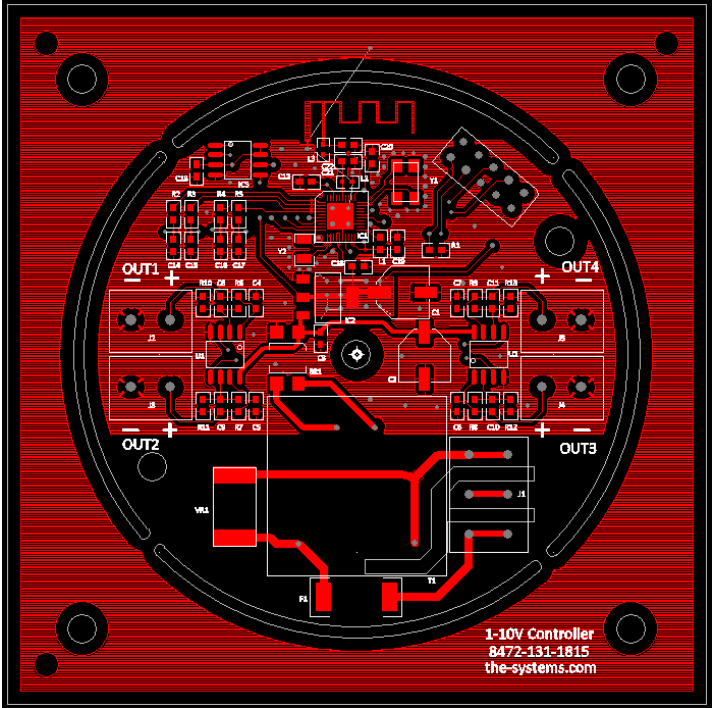


Figure 2.21. PCB top view

### 2.5.1 Mains input design

Few methods were applied to improve safety and durability of the device concerning the part of the PCB where mains power was present. To start with, copper from both sides of the PCB was removed near high voltage traces and components. This improves isolation between the high and low voltage parts of the PCB and reduces the risk of an arc-over by removing conductive material between the traces. To further improve durability against arc-over during over voltage conditions, PCB cut outs were made between mains voltage traces (Figure 2.22). Even though the dielectric strength of the FR4 material is significantly higher than that of air [24] [25], having an air gap has some benefits. Firstly, it lowers the risk of contaminants building up between the traces that could cause an arc-over. More importantly, if an arc-over should occur, it removes the possibility of permanent carbonized tracks being formed between the points where it happened [26]. This could lead to a progressive failure, where each time an arc-over occurs, the voltage required for the next one is reduced.

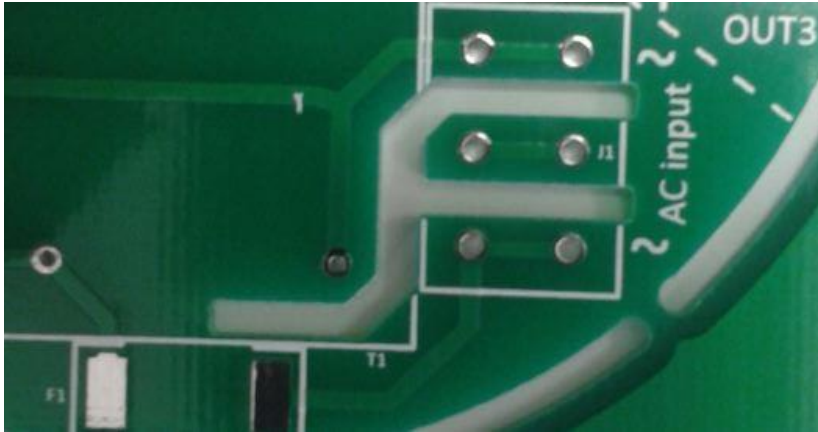


Figure 2.22. Mains input design

## 2.5.2 Crystal oscillator design considerations

The selected Bluetooth chip uses two oscillators with frequencies of 16 MHz and 32,768 kHz. 16 MHz crystal generates the clock signal for normal operation while 32,768 kHz clock is used for low power modes [12]. Oscillators are generally placed as close to the processor as possible to minimize the risk of interferences. Traces leading from the oscillator to the processor should be the same length and run parallel as much as possible to have similar impedance and to reduce delay differences [27]. Additionally, a technique known as via shielding is used to further minimize any interference [28] (Figure 2.23).

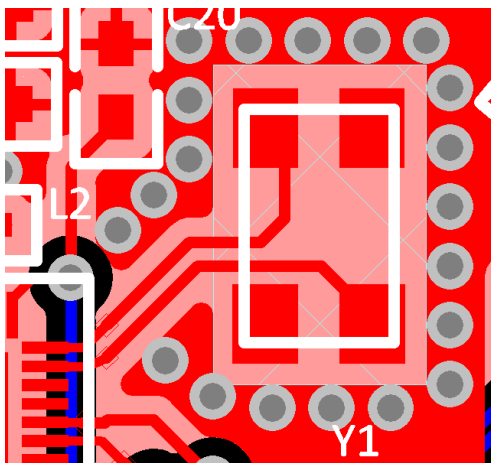


Figure 2.23. Via shielding around the 16 MHz clock

This method uses vias to surround sensitive components or traces. A via is a hole in the PCB coated with a conductive material, connecting different layers together [29]. This creates a form of vertical conductive wall around the component, reducing potential interferences [28].



In this application, it is probably not necessary, but since it does not add any cost and it takes up very little space, there is almost no reason not to do it.

### 2.5.3 Voltage regulator thermal improvement

To lower the thermal resistance from the voltage regulator to the surrounding air, a common practice of using copper areas was applied. This method utilizes copper areas on both sides of the PCB that are stitched together with multiple vias (Figure 2.24). The vias transfer heat to the other side of the board and the two areas together dissipate more heat than the component would have on its own. Furthermore, the solder mask is removed from the bottom copper area. Solder mask is a layer of polymer that PCB-s are coated with to prevent oxidation and solder from sticking on the board where it is not meant to be [30]. It is what gives the PCB its color. Removing the solder mask only gives a marginal improvement, but like with via shielding, there is practically no reason not to do it.

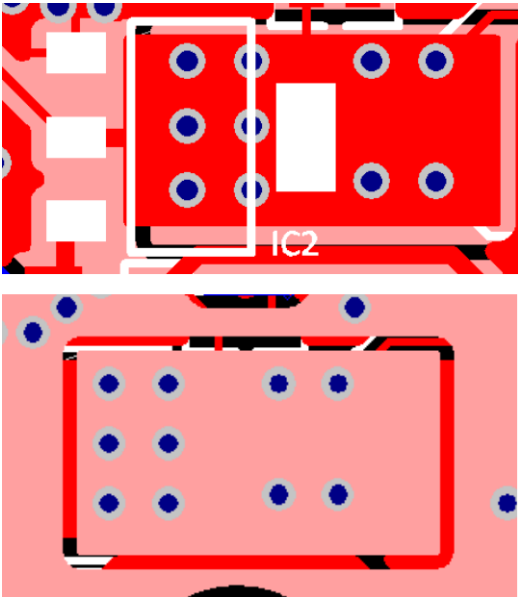


Figure 2.24. Top and bottom thermal copper areas for the voltage regulator

### 2.4.4 Trace antenna design

As the Bluetooth solution uses a chip rather than a complete module, an antenna needs to be added in order for it to work. There are external antenna modules and chips available, but it

was decided to use a PCB trace antenna. From engineering point of view, this is the most difficult one, but it has some advantages over the others. It costs nothing and it can be made in any shape or size. The company had made several Bluetooth devices before, but always with a complete Bluetooth module, so this also was an introduction to antenna design for the company. Unfortunately, it turned out that to be able to tune a custom antenna, a network analyzer is required, which the company did not have. So to start, an antenna reference design [31] provided by Texas Instruments was used. It specifies an inverted F antenna that is commonly used in mobile phones [32] (Figure 2.25). It is designed to match an impedance of  $50 \Omega$  at Bluetooth frequency of 2,45 GHz. This means ideally no matching components are need if connected to a  $50 \Omega$  source.

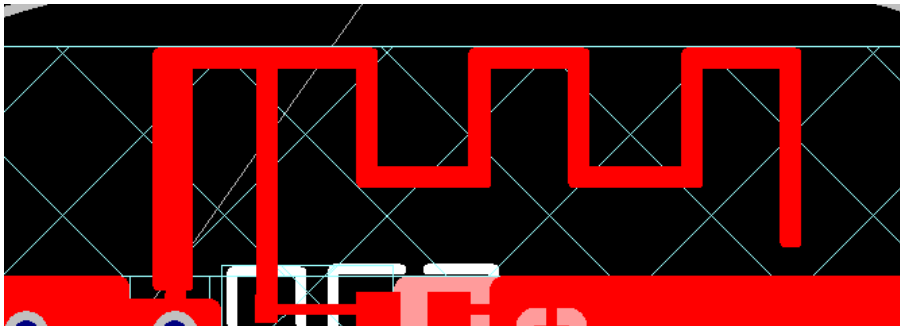


Figure 2.25. PCB trace antenna

## 2.6 Programming

Although this work concentrates mostly on the hardware design of the device, some aspects of software and programming need to be taken into account. When working with a particular microcontroller or a SOC, some specific capabilities and requirements can be important for hardware design as well.

One of the most obvious things is the pinout of the selected component, which shows what pins can be used for what function. In this case the pinout does not really matter, as the selected SOC can multiplex (Figure 2.10) most features to any output pin. This makes routing of the PCB a lot easier, as it is possible to change pins around to avoid difficult situations.

Second important thing is how to program the chip once it is mounted on the PCB. For this purpose, a pin header with 10 connections was placed on the PCB (Figure 2.26).

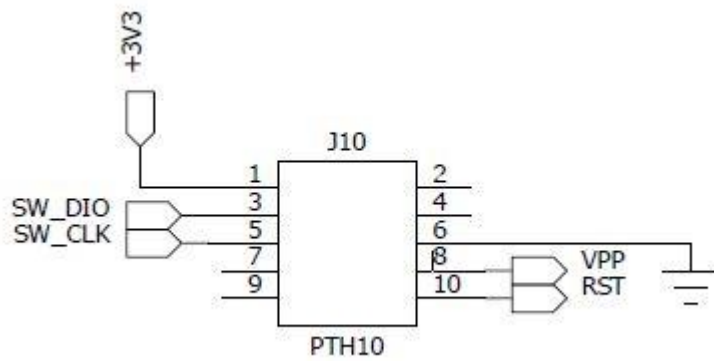


Figure 2.26. Programming header connections

Even though the current solution only uses 6 pins, the 10 pin connector for programming allows the use of a 10 pin JTAG cable. The used Bluetooth SOC also supports JTAG interface and the extra connections can be used for other communications if needed. This programming solution was chosen mostly based on the fact that the company already had the proper programming tools and connectors for this type of solution. In the future when testing different interfaces and connections on the prototype is completed, the pin header can be changed for a smaller one if needed.

For programming the prototypes, a Segger J-Link LITE emulator was used (Figure 2.27). This allowed the programming and debugging of the device from a computer by a USB cable. It supports both SWD and JTAG programming interfaces [33], so both can be tested. It cannot program the OTP memory on its own, as it cannot generate the higher voltage needed for this. To write to the OTP memory of the chip, a voltage of 6,8 V needs to be applied to a specific pin [12]. This can be done externally by an additional power supply.



Figure 2.27. Segger J-Link LITE

The goal for the future is to implement OTA programming into the device. This would allow the manufacturer to make software updates to the device once it is already programmed. The SOC already has a feature built-in that allows programming from external memory without

having to write anything into the OTP memory. When powered on, it checks if anything is written into the OTP memory and when it is blank, it will check few predefined pin configurations to see, if something is connected to them. If it finds an external memory device, it will read the program from there and write it into its system memory.

Not needing to generate the higher voltage required for writing into the OTP memory, means that the connection for it can be left out of the final design. Also, the capacitor that is used to filter the higher voltage is then no longer required. Additionally, the reset pin was only needed for debugging, so that connection can be left out of the final design as well. With OTA programming while using the SWD interface, only 4 connections are required:

- Data input/output
- Clock
- Ground
- Voltage reference

All of this combined simplifies the programming procedure and saves space on the PCB.

### 3. TESTS, MEASUREMENTS AND IMPROVEMENTS

#### 3.1 Power factor

Reactive components, like capacitors and inductors, can store energy and return it back to the source. In AC systems this can create currents that are traveling back and forth in the transmission lines without producing any real work. From the perspective of a residential consumer, this is not very important, as power companies charge only for real power. In the case of commercial consumers like factories that use a lot of power and that can have large inductive loads in the form of electric motors, power companies measure their power factor and can add extra fees based on it [34]. Even though home owners do not pay anything based on their power factor, it is still desirable to have it as high as possible, because extra current in the distribution system means further losses and lower overall efficiency.

Power factor is a dimensionless number between -1 and 1 and it is defined to be the ratio of real power to apparent power [35]. Power factor 0 means no energy is being used at the load and power factor 1 means everything is consumed by the load. Negative or positive power factor indicates the polarity of the measurement.

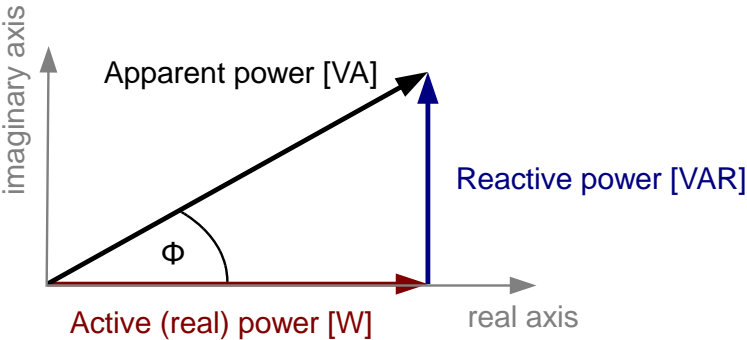


Figure 3.1. power vector diagram of pure sinusoidal waveform

In the case of a sinusoidal current waveform, the power factor is also  $\cos \phi$ , where  $\phi$  is the phase angle between the voltage and current (Figure 3.1). This is only true for pure sinusoidal waveforms, and it is known as the displacement power factor, as it only takes into account the phase angle between the voltage and current.

Non-linear loads distort the current waveform and create harmonic voltages and currents, which lower the power factor. Resulting current waveform can be very complex, but it can be represented as a Fourier series. This method describes any periodic signal as a sum on simple

sinusoidal waves, with frequencies that are integer multiples of the fundamental frequency [36]. This distortion of the current waveform by all of the harmonics is called total harmonic distortion or THD. THD is defined to be the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency [37].

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots + V_n^2}}{V_1} \tag{3.1}$$

where  $V_n$  – RMS voltage of the  $n$ th harmonic.

Knowing the THD allows us to know the true power factor of the device.

$$PF = \frac{DPF}{\sqrt{1 + THD_i^2}} \tag{3.2}$$

where PF – true power factor,

DPF – displacement power factor,

$THD_i$  – load current total harmonic distortion.

To measure power, power factors and harmonics, it is necessary to measure both voltage and current at the same time. Measurements for this device were performed with a Fluke 43B digital power quality analyzer (Figure 3.2).



Figure 3.2. Fluke 43B Single Phase Power Quality Analyzer

To measure voltage and current simultaneously, it uses regular test probes and a 10 mV/A current clamp. Because this device draws current in the range of tens of milliamperes, the sensitivity of the current clamp was not sufficient for accurate measurements. To overcome this, the conductor from which the current was being measured was looped so the conductor passed the clamp 10 times. This method utilizes the fact that the magnetic field of each turn of the loop add up [38], making it seem like 10 times higher current is flowing through the clamp. Of course this would give results that are 10 times higher, but this can be corrected in

the meter software. Selecting current clamp sensitivity 10 times higher than it actually is will cancel out the effect of looping the conductor through the clamp, leaving only increased current sensitivity.

### 3.1.1 Power and power factor measurements

Measuring the prototype gave the following results (Figure 3.3):

- Power 1,0 W
- Power factor 0,76
- Displacement power factor 0.80
- Current 5,4 mA

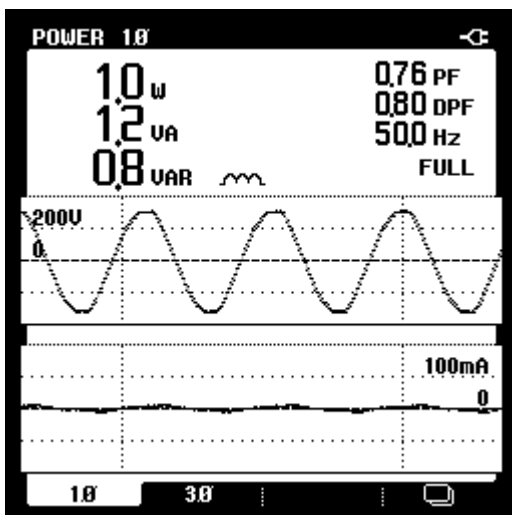


Figure 3.3. Power and power factor measurement

Adding LED drivers to the output and changing the output voltages had no effect on the measurements. The power factor and displacement power factor were similar, which means that THD is probably low and the power factor is mainly determined by the phase angle between the voltage and current. Since the instrument can measure voltage and current at the same time, their waveforms can be analyzed (Figure 3.4).

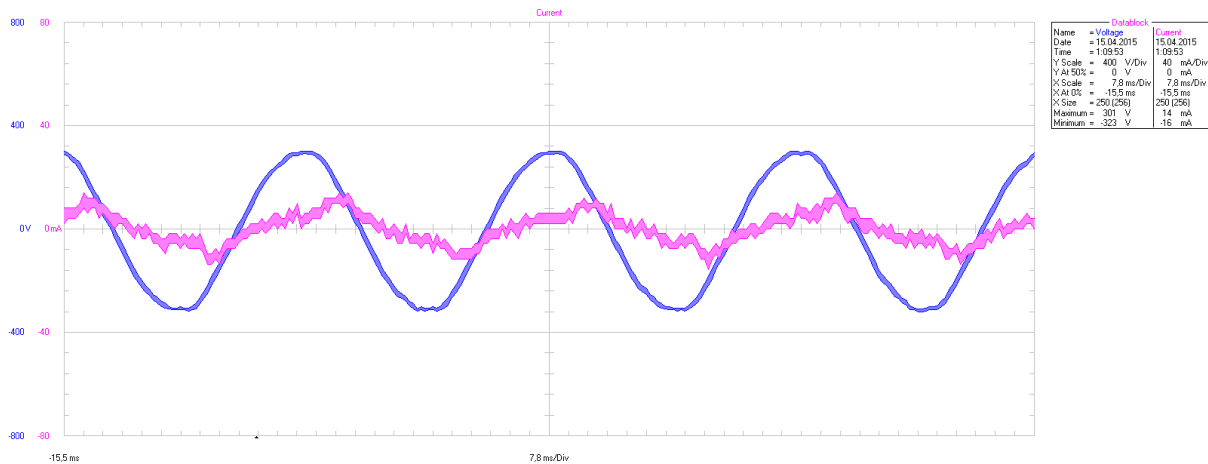


Figure 3.4. Voltage and current waveforms

It is clear from looking at this waveform that the current is lagging behind the voltage, meaning that the load is inductive.

Even if the power factor was much worse than 0,76, it would not make much of a difference. The current is so low it would be insignificant compared to everything else in an average household. Nevertheless, it was decided to try to improve the power factor. This is known as power factor correction, and it is an important part of electronic design. At the very least the knowledge and experience gained can be applied to other products in the future.

The load is inductive, so capacitance needs to be added to compensate for it. Capacitance and inductance have the opposite effect on the phase angle between the voltage and current [39]. The right amount of capacitance to cancel out the effect of the inductance was found by trial and error. At first, a 100 nF capacitor was added in parallel with the inputs of the device (Figure 3.5).

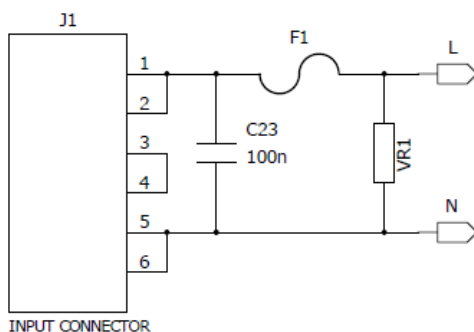


Figure 3.5 Capacitor parallel with the inputs



While technically any non-polarized capacitor with the appropriate voltage rating might work in this situation, it is best to use specific capacitors meant for these kinds of applications. These are known as AC safety capacitors or X/Y capacitors based on their ratings. They are meant to handle high voltage impulses and they do not create an electric shock risk when they fail [40].

100 nF was too much and the current started to lead the voltage (Figure 3.6) and the power factor remained the same.

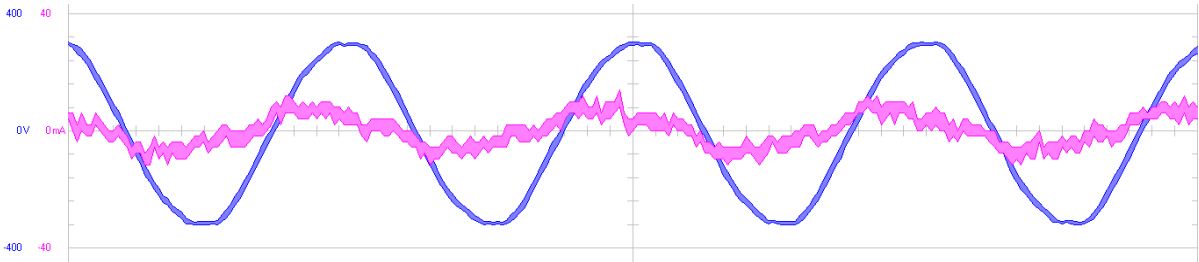


Figure 3.6. Current leads the voltage

Since the current started to lead the voltage about the same amount as it was lagging the voltage before, it was clear the capacitance needed to be about half of what was used. A 50 nF capacitor matched the current and voltage waveforms perfectly (Figure 3.7).

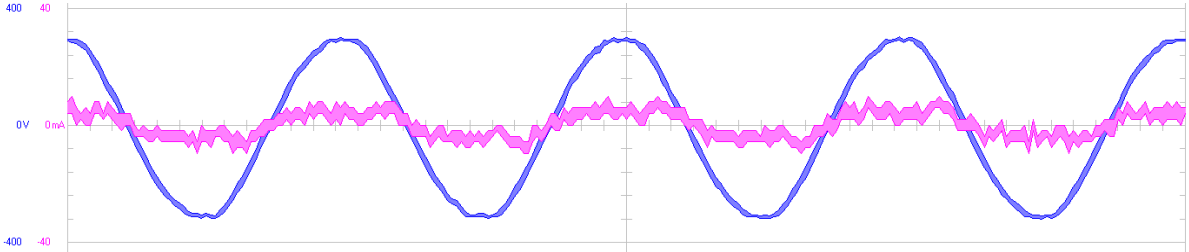


Figure 3.7. Current and voltage waveforms are in phase

Measuring the power factor with the 50 nF capacitor gave a much better result than before. The power factor was 0,95 and the displacement power factor was 1,00 because the voltage and current were in phase (Figure 3.8).

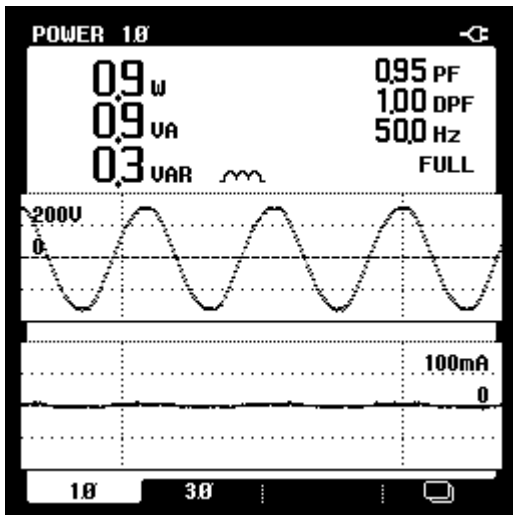


Figure 3.8. Power factor measurement after corrections

### 3.1.2 Harmonics measurements

Even though the phase angle is 0 between the voltage and current, the power factor is still not 1. This is because of the current harmonics. The instrument used for measurements is capable of measuring harmonics up to the 49th harmonic (Figure 3.9). The EN 61000-3-2 standard does not specify harmonic current limits for lighting equipment for LED-s that have lower active power than 25 W [41]. Even so, the harmonics are low (Figure 3.9) and there is no need to add a filter on the input to reduce them even further.

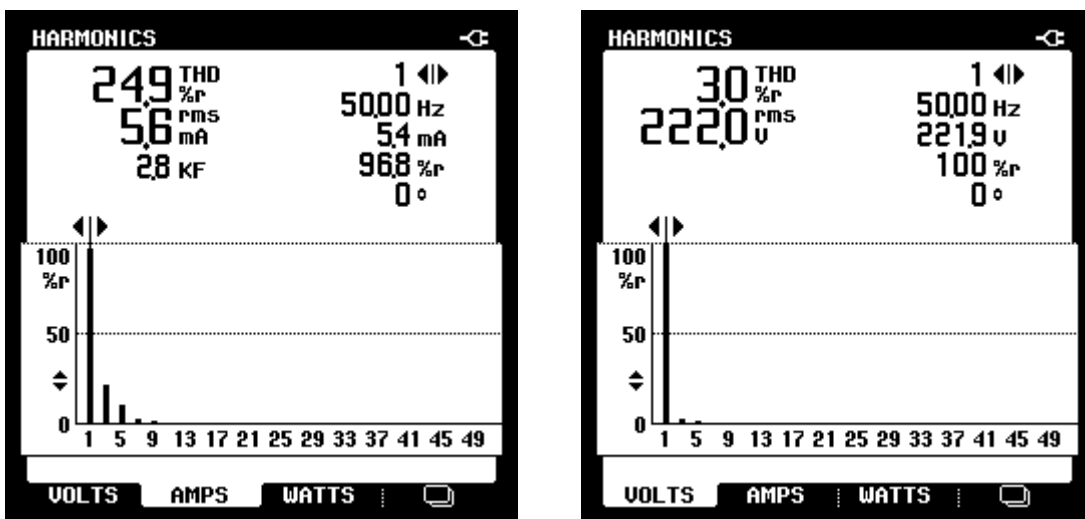


Figure 3.9. Current (left) and voltage (right) harmonics of the device

## 3.2 Input voltage measurements

To evaluate the performance of the voltage regulation solution, the voltages were measured and analyzed with an oscilloscope. Since the voltage before the fixed output regulator is used to power the operational amplifiers (Figure 2.4), both voltages before and after the regulator are of interest.

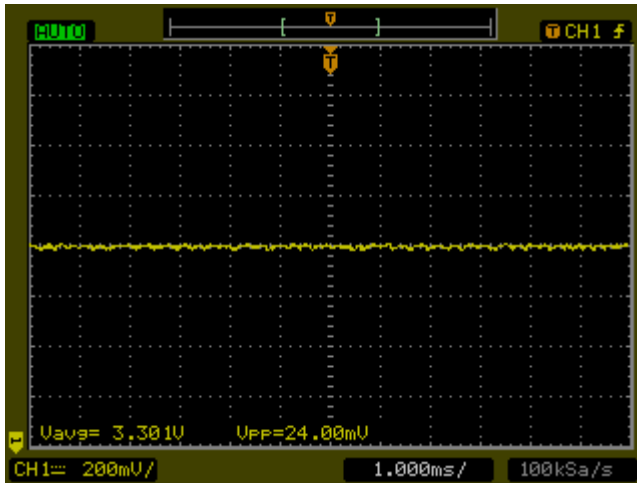


Figure 3.10. 3,3 V output of the voltage regulator

The output of the regulator is very stable and works exactly as intended (Figure 3.10). The voltage is precisely 3,3 V and the peak-to-peak ripple voltage is around 24 mV. It might even be possible to change the output capacitor with a smaller and cheaper one while keeping the ripple voltage within acceptable levels.

Measuring the voltage before the regulator revealed a ripple voltage of over 500 mV (Figure 3.11). While the device worked with this ripple voltage without any serious problems, it would be preferable to smooth out the voltage to increase stability of the operational amplifiers. For this purpose, a 220  $\mu\text{F}$  capacitor was added to the already existing 100  $\mu\text{F}$  capacitor. This lowered the ripple voltage considerably to below 200 mV (Figure 3.11).

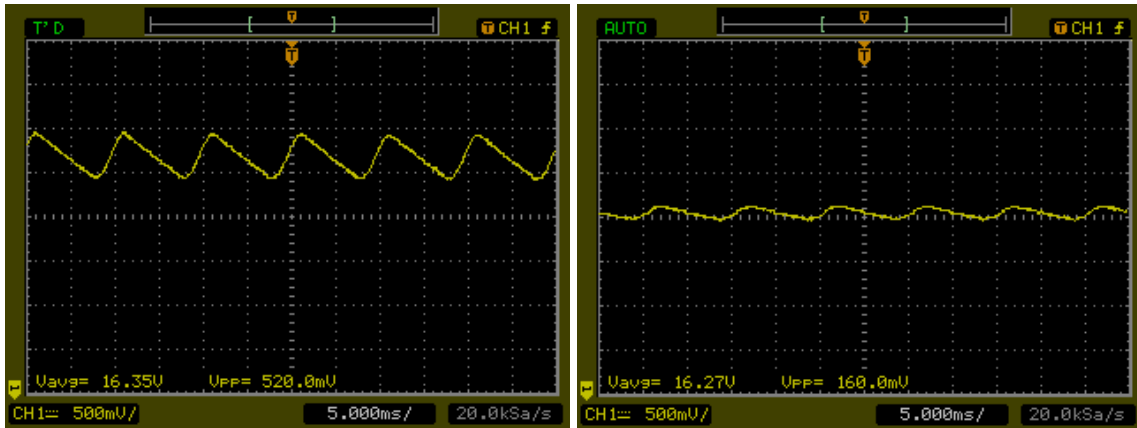


Figure 3.11. Ripple voltage with 100  $\mu\text{F}$  (left) and 320  $\mu\text{F}$  (right) capacitance

To avoid having to redesign the PCB to accommodate for a larger capacitor, the replacement capacitor would need to be the same size as the one already used. This along with the fact that the capacitor needs to be rated for the proper voltage, which in this case is at least 25 V, sets limits to the capacitors that are suitable. Biggest capacitors readily available that meet these criteria are 220  $\mu\text{F}$ . This increase in capacitance only lowered the ripple voltage to about half of what it was before (Figure 3.12). Since the cost of the two capacitors is almost the same, there is no reason not to switch the original capacitor with the larger one.

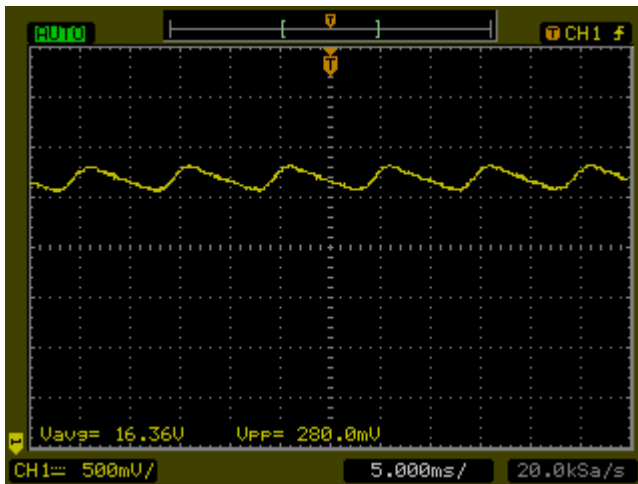


Figure 3.12. Ripple voltage with a 220  $\mu\text{F}$  capacitor

### 3.3 Bluetooth range assessment

To properly measure the transmitter properties like efficiency, insertion loss, impedance or radiation pattern, specialized equipment and rooms are necessary. Since these were not

available during the design process, some basic measurements were made using a smart phone and the received signal strength indicator of the device. It shows the received signal strength in dBm [42].

Naturally, this kind of measurement is highly inaccurate, because it takes into account noise and reflections, but it should give a rough estimate on how well the antenna is working. With clear line of sight to the device inside a building, it was possible to control the device over 50 m away without problems. With walls between the device and the smart phone, it was possible to control it while being over 10 m away in a different room. The orientation of the device affected the performance. While the antenna was perpendicular with the direction from the phone, it worked slightly better than when it was parallel. The difference was small but the device is intended to be mounted vertically anyway, so it is perpendicular to devices inside the room.

This was much better than expected and it gives confidence that the antenna is working well. The ranges achieved while testing are more than enough for the intended purpose of the device.

### 3.4 1 V - 10 V output measurements

To goal was to generate smooth DC voltages up to 10 V at the outputs. To measure the quality of the outputs and to see how well the low-pass filter was performing, an oscilloscope was used (Figure 3.13).

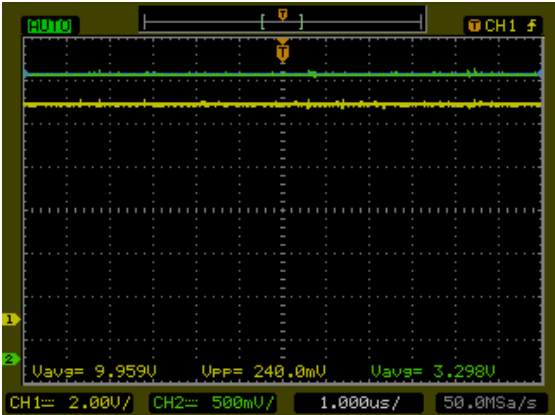


Figure 3.13. Amplifier input (CH2) and output voltage (CH1) at maximum without an LED driver connected

When the output was set to maximum, the low-pass filter was giving out 3,3 V and the amplifier output was nearly 10 V with only 240 mV of peak-to-peak ripple. Connecting an LED driver to the output did not change anything. The voltages were correct and the waveforms were smooth, meaning the output circuit works as intended when at maximum. Measuring the outputs at minimum revealed a slight problem.

The 1 V - 10 V inputs of LED drivers usually have a voltage generated by the drivers themselves. This is to allow the use of simple potentiometers for dimming. If the inputs are not connected to anything, then the light is at its maximum because the resistance between the inputs is effectively infinite in any practical sense. When the inputs are connected to each other with no resistance, then the light is at its minimum. This creates a problem when trying to turn the light down to minimum, because the source that generates the bias voltage in the dimmer is strong enough to pull the output up to about 0,6 V (Figure 3.15). There is a noticeable difference in the brightness of the light between when 0,6 V and 0 V are at the input. To compensate for it, pull-down resistors were added on the outputs (Figure 3.14). By testing different resistors values on the outputs, a maximum resistance value was found that was able to correct the outputs.

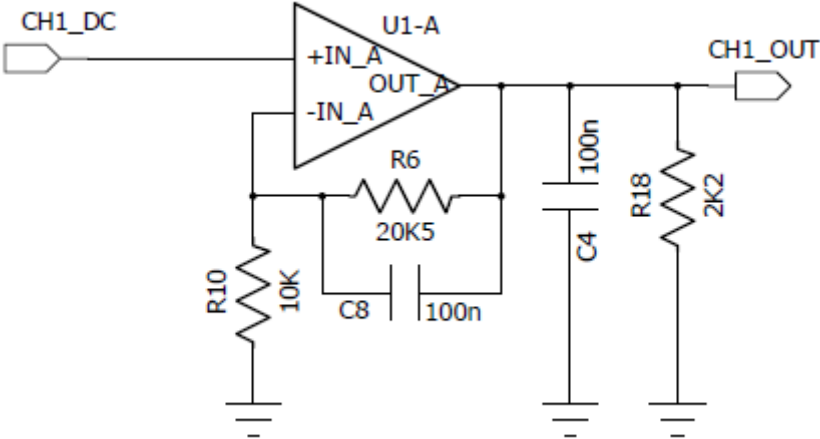


Figure 3.14. Pull-down resistor (R18) for the output

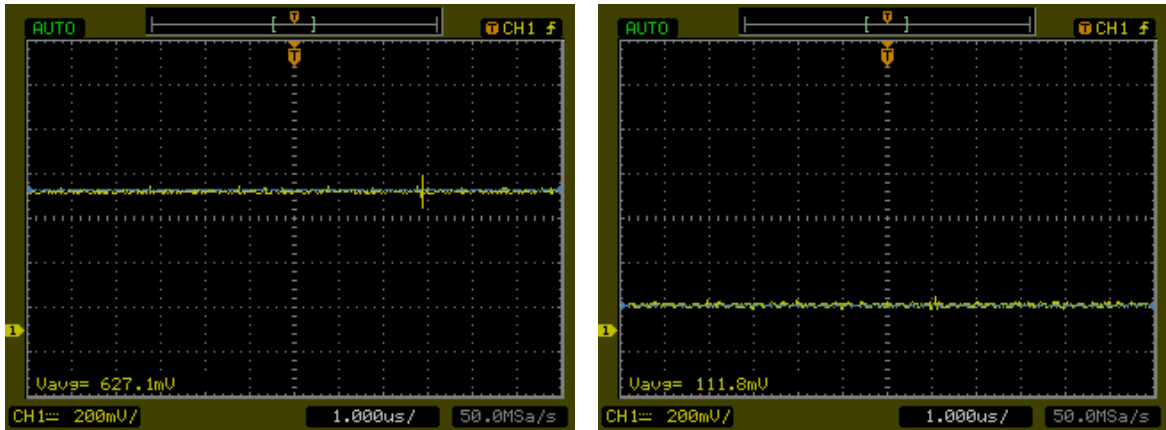


Figure 3.15. Output at minimum without pull-down resistor (left) and with a pull-down resistor (right) when connected to an LED driver

Although the 2,2 k $\Omega$  pull-down resistor lowered the voltage down to around 0,1 V (Figure 3.15) , it was enough. There was no noticeable difference in the brightness of the light when the output was at 0,1 V or 0 V. Also, the resistor did not affect the performance of the output when at maximum.

## 4. PRODUCTION COST

One of the requirements for this device that was set from the beginning was low production cost. The production cost can be divided into five main categories for this device:

- Cost of the components
- Cost of PCB manufacturing
- Cost of PCB assembly
- Cost of the casing or mounting frame
- Cost of final assembly and packaging

As this work focuses only on the electronic part of the product, the cost of the casing or mounting frame and final assembly plus packaging are not considered.

The component cost is calculated based on the prices of European electronic component distributors. As prices go down when quantities go up, prices for production of different quantities are calculated.

No.	Component	Quantity	Description	Price [€] (order quantity 10)	Price [€] (order quantity 100)	Price [€] (order quantity 1000)
1	DA14580	1	BLUETOOTH SOC	3,610	3,610	3,410
2	AP1117E33G-13	1	LDO, REG, 3.3V	0,280	0,182	0,137
3	SST25PF020B-80-4C	1	FLASH, 2MBIT	0,640	0,600	0,540
4	LM358DRG3	2	OP-AMP, GENERAL	0,280	0,085	0,064
5	CPF0603F20K5C1	8	20K5, 1%	0,010	0,009	0,003
6	MCWR06X1002FTL	4	10K, 1%	0,001	0,001	0,001
7	MCWR06X2201FTL	4	2K2, 1%	0,001	0,001	0,001
8	V430CH8	1	VARISTOR, 8J, 275VAC	0,930	0,790	0,551
9	EEEFTE221XAP	2	CAP, ALU, 220UF, 25V	0,350	0,196	0,142
10	MC0603B104K250CT	15	CAP, MLCC, 100NF, 25V	0,004	0,003	0,002
11	MC0603B105K160CT	3	CAP, MLCC, 1UF, 16V	0,030	0,020	0,020
12	MC0402N1R0C500CT	2	CAP, MLCC, 1PF, 50V	0,009	0,009	0,005
13	MB6S-E3/45	1	RECTIFIER, 600V, 0.5A	0,290	0,250	0,210



14	FQ5032B-16.000	1	CRYSTAL, 16.0MHZ	1,050	1,050	0,800
15	LFXTAL009678	1	CRYSTAL, 32.768KHZ	0,670	0,470	0,360
16	BV2010136	1	0.35VA, 230VAC, 12V	1,950	1,700	1,700
17	0242.125UR	1	FUSE, SMD, 125MA	2,350	1,960	1,830
18	MLZ1608A2R2WT	1	INDUCTOR, 2.2uH	0,096	0,075	0,069
19	MCFT0BT3N9	1	INDUCTOR, 3.9nH	0,054	0,044	0,039
20	36541E5N1JTDG	1	INDUCTOR, 5.1nH	0,247	0,221	0,156
21	AST2150302	1	TERMINAL BLOCK, 3POS	2,030	1,100	0,970
22	PM5.08/2/90 BLK	4	TERMINAL BLOCK, 2POS	0,520	0,440	0,250
<b>Total:</b>				<b>17,79</b>	<b>14,58</b>	<b>12,32</b>

Table 4.1. Bill of materials for the device

Two main options are available for PCB manufacturing. These are ordering the PCB from China or from local manufacturers. The companies experience has shown that ordering from China is a lot cheaper even when taking the cost of transportation into account. There is not much difference in terms of quality of the PCB between the two options and the only downside of ordering from China is the slightly longer delivery time. For production, this is not an issue as the PCB-s can be ordered in advance. Based on previous orders of similar PCB-s from China and from local manufacturers, the cost can be estimated.

<b>Manufacturer</b>	<b>Cost per PCB [€] (order quantity 10)</b>	<b>Cost per PCB [€] (order quantity 100)</b>	<b>Cost per PCB [€] (order quantity 1000)</b>
China	5	2	1
Local	7	5	2

Table 3.2. Estimated cost of PCB production

The company has only used local manufacturers for PCB assembly, so the cost is estimated based on their prices. As per initial requirements, the components are mounted only on one side and are mostly surface mounted. This means most of the components can be placed and soldered with one procedure. However, there are some through-hole components like the connectors and the transformer. These need to be added by hand afterwards. Based on previous experience, the cost of assembling the PCB should be roughly 5 € per one board if the quantity is around 100.

Assuming that the PCB-s are ordered from China, the total cost of the electronics for this device can be calculated.

<b>Category</b>	<b>Cost per PCB [€] (order quantity 10)</b>	<b>Cost per PCB [€] (order quantity 100)</b>	<b>Cost per PCB [€] (order quantity 1000)</b>
Components	17,79	14,58	12,32
PCB manufacture	5	2	1
PCB assembly	5	5	5
<b>Total:</b>	<b>27,79</b>	<b>21,58</b>	<b>18,32</b>

Table 3.3. Estimated cost of production of electronics

Even though there was no specific cost set in the beginning, the estimated costs are a little higher than hoped for. When producing 100 devices, the cost of electronics per one device should ideally be under 15 €. This is still achievable, since it should be possible to get some of the more expensive components cheaper if a deal can be made with the distributors or the manufacturers directly. Also, it might be possible to further reduce the cost by switching out some components with cheaper ones, if the decrease in quality or performance is acceptable.

When calculating the total costs, it is clear that the choices made regarding component selection in the beginning were justified. Especially concerning the Bluetooth solutions that were considered. Complete Bluetooth Smart modules can cost upwards of 10 €, which is almost the total cost of the components in the current solution, including the Bluetooth SOC.

# 5. CONCLUSIONS

The aim of this work was to develop the electronics part of a device that could wirelessly control LED drivers that are widely used for lighting solutions. It started with research into already existing products and possibilities on how to differentiate it from them. After the main objectives of it being small, energy efficient and able to be mounted inside of an electrical mounting box were set, the design work began. First was the circuit design portion, where different components and solutions were studied and compared. When this was done then a PCB was designed for the device. In that part various techniques for improving the design were researched and implemented. After finishing the PCB a few prototypes were ordered and assembled. These prototypes were used to test many functions of the device and improvements and changes were made where necessary. These test and measurements offered a great opportunity to put the theory learned and applied in the design phase into practice, and see how the used methods really performed.

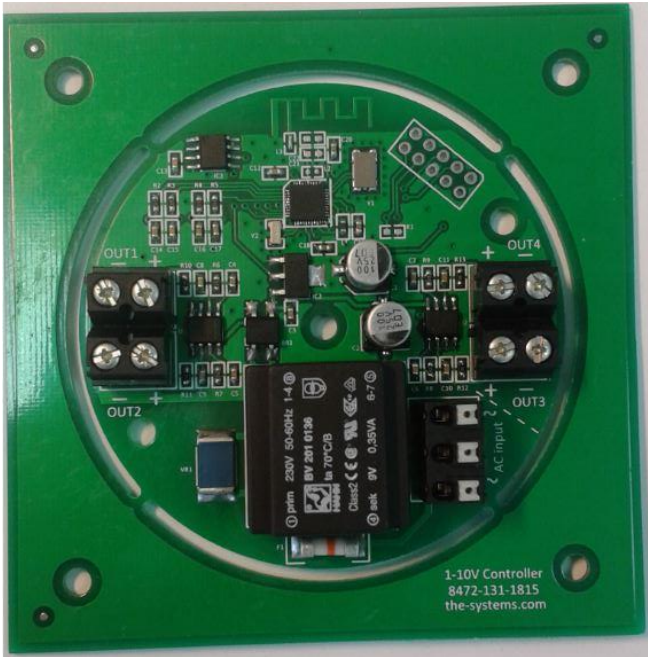


Figure 5.1 PCB with components mounted

Unfortunately, since the company did not have the proper equipment to design a new antenna and measure its properties, the radio-frequency engineering part remained largely theoretical. Nevertheless, the knowledge gained from researching this topic offered a great introduction into antenna design and everything that goes along with it. The company has been using only

complete Bluetooth modules for its products until now, and depending on the performance of the cheaper chip solution, it might start to use it instead of the modules.

The developed device can be used as a platform for added features or new similar products. With few hardware changes it is possible to make it work with DALI interface instead of the 1 V - 10 V interface. Possibilities of adding switching features or LED dimming by PWM were already explored in this work and can be added in the future if needed. Additionally, a small battery can be added, which would allow the device to keep track of time reliably. This would allow the user to program actions like turning the lights on or off at certain times.

The selected Bluetooth interface allows this device to be used for home automation. At its most basic form, this device allows the user to control their lighting wirelessly. However, software features can be added in the future to allow for automatic fading or switching on or off depending on the time and date. With small hardware additions it would be easy to integrate motion or light sensors with the device. This would allow for automatic switching or dimming based on movements or ambient light levels. By adding Bluetooth central device functionality to the device, it would be possible for multiple devices to communicate with each other. This would make possible the controlling of devices that are not currently in range of the user and to further automate the lighting solution in a household. Other devices that do not have any sensors attached can receive information from the ones that do have sensors. It would let the user to monitor and control all of the lights that are connected to these devices while being connected to only one of them. Still, this would not permit to change the lights that are not in range in real time, as Bluetooth does not allow for one device to be a peripheral and a central device at the same time. The device would need to disconnect from the central device that is used to control it, and then connect with other of its kind to send the information.

While designing the product, the target was to meet few standards that are common among devices that deal with controlling LED lights. One problem regarding the standards was the classification of the device. Some of the mentioned standards only apply to LED lights or the power supplies and dimmers that control these LED lights. The device designed in this work controls the power supply which in turn controls the LED-s. Since it does not control or power any lights directly, it is difficult to understand what standards or aspects of them apply to it. Some key requirements from these standards were taken into account in the design process as best as possible. However, these standards are rather complicated and hard to

evaluate, so full tests by a third party would be necessary in the future to confirm compliance with the desired standards. Meeting these standards would give the basis for CE marking declaration, which would allow the device to be sold and transported freely within the European Economic Area.

In general, the objectives set for the work were accomplished. The designed device works well and meets all of the requirements that were established. The design process gave a lot of knowledge and experience in electronic design. While the radio-frequency engineering part was mainly theoretical, it still provided a great deal of useful information for future applications. Likewise with power factor correction, which was not necessary and rather basic in this case, but it provided theoretical knowledge and some real life experience that can be useful in other designs. Another important benefit was getting to know some standards and the legal aspects of getting a product on the market in the European Union. All things considered, the work done was satisfactory.

## 6. KOKKUVÕTE

Töö eesmärk oli välja arendada elektroonika osa seadmele, mis võimaldaks laialdaselt levinud LED toiteplokkide juhtmevabalt juhtida. Töö algas olemasolevate seadmete ja lahenduste uurimise ja tutvumisega. Selgitati välja, mis on juba olemas ja mida võiks paremini teha. Peale seda määrati arendatavale seadmele põhilised nõuded, milleks oli 1 V - 10 V liides, madal energiatarve, väikene suurus ja võimalus paigaldada elektriinstallatsiooni harutoosi. Kui eesmärgid olid paigas, algas seadme projekteerimine. Esimene ülesanne oli elektroonika skeemi loomine. Selles osas uuriti erinevaid lahendusi ja komponente ning võrreldi nende eeliseid ja puuduseid. Kui skeem oli valmis, algas trükkplaadi disain. Selles peatükis uuriti ja kasutati mitmeid tehnilisi lahendusi, mis parandavad seadme töökindlust. Kui trükkplaadi disain oli valmis, loodi tootmiseks vajalikud failid ja telliti trükkplaadid ning komponendid, millest siis koostati mõned seadme prototüübid. Neid prototüüpe kasutati seadme mitmete funktsioonide katsetamiseks ja mõõtmiseks. Tulemuste alusel muudeti ja täiustati kasutatud lahendusi. Mõõtmiste tegemine pakkus head võimalust näha, kuidas projekteerimise käigus õpitud teooria ja kasutatud lahendused reaalselt töötasid.

Kuna ettevõttel ei olnud vajalikke seadmeid antenni arendamiseks ja mõõtmises, jäi raadiotehnika osa põhiliselt teoreetiliseks. Sellest hoolimata, pakkus selle teema uurimine hea sissejuhatuse raadiotehnikasse. Ettevõtte on siiani kasutanud oma toodetes ainult komplektseid Bluetooth mooduleid, kus on antenn juba sisse ehitatud. Kui antud seadmes kasutatud odavam Bluetoothi lahendus on edukas, võib ettevõtte tulevikus seda ka teistes toodetes kasutama hakata.

Arendatud seadet saab kasutada platvormina uute võimaluste lisamiseks või üldse uue sarnase toote loomiseks. Paari riistvaralise ja tarkvaralise muudatusega on võimalik seadet kasutada DALI liidesega 1 V - 10 V liidese asemel. Toiteplokkide sisse ja välja lülitamist ja LED-ide juhtimise võimalust PWM-iga juba käsitleti selles töös, ning neid saab vajaduse tekkimisel tulevikus lisada. See eristaks seda seadet teistest sarnastest valgusregulaatoritest veel enam, kuna 1 V - 10 V liides ei võimalda valguse täielikku väljalülitamist. Lisaks, kui seadmele lisada patarei, oleks võimalik kella ja kuupäeva probleemideta jälgida. See lubaks kasutajal programmeerida kellaajalisi tulede lülitusi ja muid funktsioone.

Kasutatud Bluetoothi liides võimaldab antud seadet kasutada koduautomaatikaks. Kõige lihtsamal vormis, võimaldab seade kasutajal oma valgustust juhtmevabalt reguleerida. Tarkvaraliselt saab tulevikus lisada võimalusi tulede automaatseks juhtimiseks vastavalt kellaajast. Lihtsate riistavarliste täiendustega on võimalik seadmele lisada liikumis- või valgusandurite kasutamise tugi. See võimaldaks tulede programmeerimist vastavalt liikumisele või valgustatuse tasemele. Kui lisada Bluetoothi keskjaama funktsionaalsus või teha eraldi selline seadme versioon, saaksid mitmed seadmed omavahel suhelda. Lisaks võimaldaks selline lahendus kasutajal juhtida seadmeid, mis ei ole hetkel temaga ühenduse ulatuses, ning veel rohkem kodust valgustuse süsteemi automatiseerida. Näiteks seadmed, millel ei ole andureid küljes, saaksid infomatsiooni teistelt seadmetelt, millel on vastavad andurid. See võimaldaks kasutajal jälgida ja juhtida kõiki seadmeid ja valgustust, olles ühenduses ainult ühega neist. Kahjuks ei võimaldaks selline lahendus kasutaja ühenduse ulatusest väljas olevaid seadmeid reaalajas juhtida. Seda sellepärast, et Bluetooth ei võimalda ühel seadmel olla nii keskseade kui ka välisseade. Kasutajaga ühenduses olev seade peab ühenduse katkestama ja siis teiste välisseadmetega ühenduse looma, et infomatsiooni edastada.

Seadet projekteerides oli eesmärk saavutada vastavus mõningate standarditega, mis on levinud LED valgustust juhtivate toodete hulgas. Lisaks muidugi mõned üldohutus ja elektromagnetilise ühilduvuse standardid, mis on olulised kõikidele elektroonika seadmetele. Standardite kasutamist raskendas asjaolu, et antud seadet on raske klassifitseerida. Paljud standardid kehtivad LED valgustusele või seadmetele, mis otseselt juhivad LED valgustust, nagu toiteplokkid või valgusregulaatorid. Antud seade aga ei juhi valgustust otseselt, vaid juhib toiteplokki, mis omakorda juhib valgustust. Selle tõttu on raske aru saada, millised standardid kehtivad selle kohta või mis osad nendest standarditest on kohased. Tähtsamaid nõudeid nendest standardidest üritati sellegipoolest järgida projekteerimise protsessis nii hästi kui võimalik. Siiski, need standardid on keerulised ja vastavust on kohati raske hinnata. Prototüüpide täielikul valmimisel tuleks vastavust soovitud standarditele lasta kontrollide mingi kolmanda osapoole poolt. Nendele standarditele vastavus annaks alust eeldada vastavust kohustuslikele Euroopa direktiividele, mis võimaldaks seadmele CE märki deklareerida. CE märk lubaks antud seadet vabalt müüa ja transportida terves Euroopa Majanduspiirkonnas.

Üldiselt, töö alguses seatud eesmärgid said täidetud. Seade töötab hästi ja vastab kõigile satud nõuetele. Elektroonika projekteerimine andus palju kasulikke teadmisi ja kogemusi

elektroonika alal. Kuigi raadiotehnika osa oli põhiliselt teoreetiline, andis seegi palju väärtuslikke teadmisi, mis tulevad tulevikus kindalsti kasuks. Samuti nagu ka võimsusteguri parandamine. See ei olnud otseselt vajalik antud seadme puhul, kuid sellest saadud teadmised ja kogemused tulevad edasiste tööde juures kindlasti kasuks. Tähtis osa oli ka standardite ja õigusaktidega tutvumine. Tööd tehes sain teada Euroopa direktiividest ja nende tähtsusest uue toote turule toomises. Lisaks, kuidas vajalikele direktiividele vastavust demonstreerida ja mida on vaja teha, et vastavust deklareerida. Kokkuvõtvalt võib tehtud tööga ja saadud tulemustega rahule jääda.



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## **APPENDIX A Example of EC Declaration of Conformity**

### **EC Declaration of Conformity**

**The equipment which accompanies this declaration is in conformity with EU**

**Directive(s):**

2006/95/EC Low Voltage Directive

2004/108/EC Electromagnetic Compatibility Directive

**Manufacturer:**

THE Systems LLC, Rävåla pst 8-B208, Tallinn 10143, Estonia

**A copy of the Technical file for this equipment is available from:**

Rävåla pst 8-B208, Tallinn 10143, Estonia

**Description of Equipment:**

1 V – 10 V Bluetooth LED light controller, serial number 8472-131

**The following harmonized standards have been used:**

EN 61347-1 General and safety requirements for lamp controlgear

EN 61347-2-13 Particular safety requirements for DC or AC supplied electronic controlgear for LED modules

EN 62384 Performance requirements for electronic controlgear for LED modules

EN 61000-3-2 Electromagnetic compatibility – limits for harmonic current emissions

EN 61000-3-3 Electromagnetic compatibility – limits for voltage changes and flicker

EN 61547 Electromagnetic immunity requirements

EN 55015 Limits of radio disturbance

**The last two digits of the year in which the CE marking was affixed: 15**

**Authorized signatory of manufacturer:**

Signature

Name of signatory

Position in company

Place and Date

**APPENDIX B Photos of the prototype**

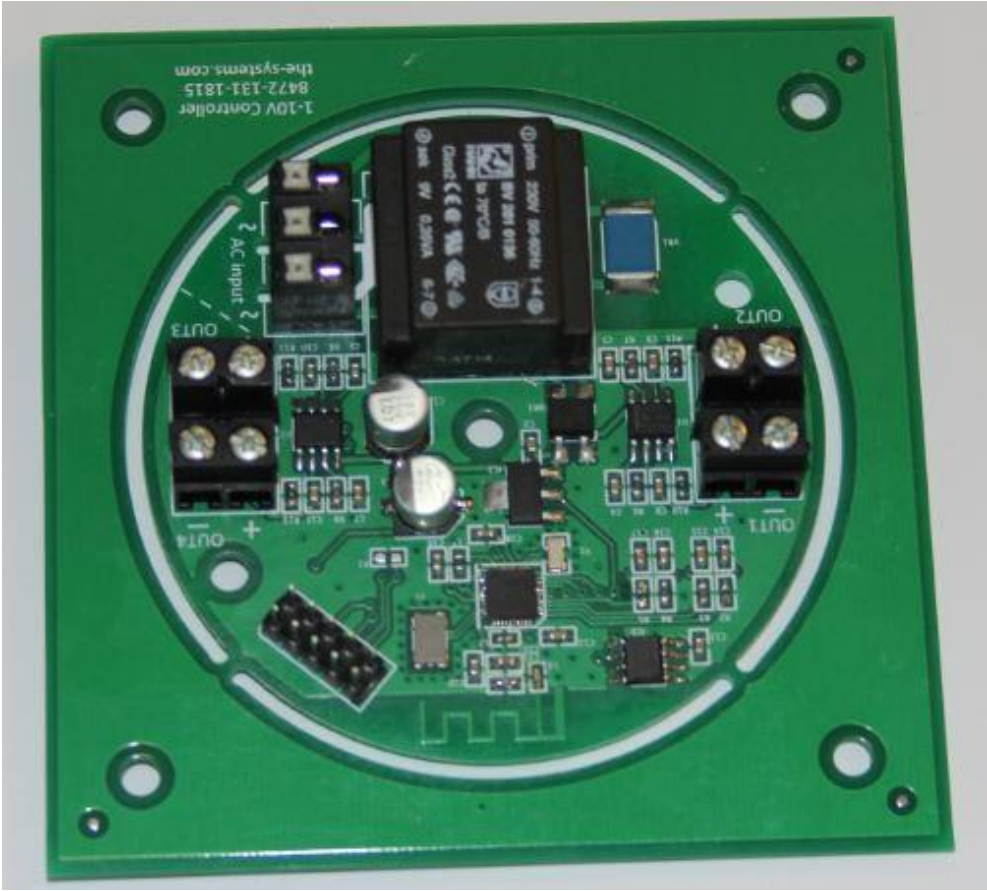


Photo 1. Top view

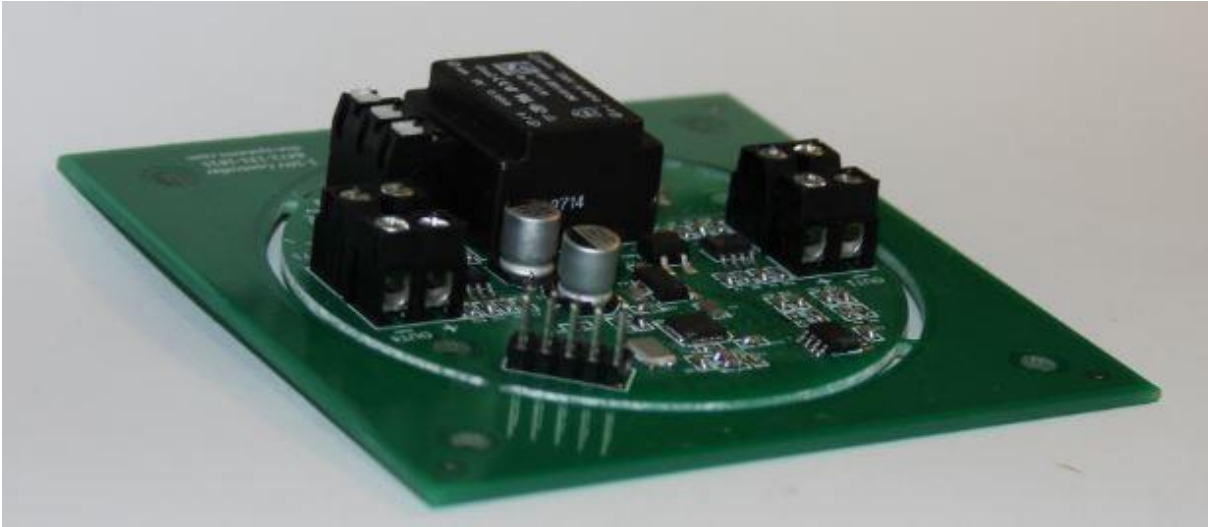


Photo 2. Side view



Photo 3. Bottom view