HOGESCHOOL ROTTERDAM

ELECTRICAL ENGINEERING

Smart Dimmer

Crownstone

Internship Report

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December 20, 2021

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Summary

Crownstone is an innovative company based in Rotterdam, designer and manufacturer of smart plugs and connectors with a focus on indoor positioning of smartphones and wearables.
To offer a more complete range of products, Crownstone wants to expand its smart home product line with a smart wall switch and wall dimmer. In developing this product, Crownstone is collaborating with a company that specializes in product development in home automation. While Crownstone will focus on electronics, the collaboration partner will provide 3D models and prototypes for the housing.

It's essential that the wall dimmer operate without using a neutral wire since the switch boxes in older homes are only equipped with a live and switching wire to the lamp. Besides that, the dimmer should dim both energy-efficient LED lights and conventional lamps. In order to realize a prototype in this assignment, the report will start with a theoretical study of the topic. First, the research will focus on different techniques used for dimming AC signals. Then on methods for supplying the circuit with power, without using a neutral wire.
The report will first focus on options to power the device using stored energy, such as a battery or capacitor. After that on possibilities to harvest energy for powering the device.

Samenvatting

Crownstone, gevestigd te Rotterdam, is ontwerper en fabrikant van slimme stekkers en connectoren (kroonsteentjes). Waarbij de focus ligt op positiebepaling van smartphones en wearables binnenshuis.
Crownstone wil door het assortiment uit te breiden naar slimme wandschakelaars en wanddimmers een nog completer assortiment aanbieden. Bij het uitwerken van dit product werkt Crownstone samen met een bedrijf dat zich specialiseert in productontwikkeling op het gebied van domotica. Waar Crownstone zich zal richten op de elektronica, levert de samenwerkingspartner 3D-modellen en prototypes voor de behuizing.

Het is van belang dat de wanddimmer moet kunnen werken zonder neutrale draad, omdat er in oudere woningen vaak enkel een fase en schakeldraad op de plaats van de inbouwdoos te vinden is. Verder moeten er zowel energiezuinige ledlampen als conventionele lampen gedimt kunnen worden.

Om in deze opdracht een prototype te realiseren, zal er in het verslag eerst een theoretische verdieping worden gedaan. Allereerst zal dit onderzoek zich richten op verschillende technieken gebruikt om te dimmen bij een wisselspanningsbron. Daarna op het voeden van het circuit zonder gebruik te maken van een nuldraad. Hierin zal eerst de focus liggen op het opslaan van energie en daarna op het verkrijgen ('oogsten') van energie uit de omgeving van het apparaat.

1 Introduction

This chapter describes the assignment of the internship and gives a brief description of Crownstone.

1.1 About Crownstone

Crownstone, an innovative company based in Rotterdam, builders of smart plugs and connectors (Dutch: kroonsteentjes). Crownstone develops small form factor modules which can be put behind a power outlet. This module is a 16A switch, LED dimmer, power meter, soft-fuse, standby-killer and presence sensor in one device. The unique selling point is the indoor localisation of smartphones and wearables, which makes it possible to automatically turn on and off or dim lights based on the user's presence.

1.2 Problem definition

Crownstone would like to expand its product line around smart home products. The available Crownstone modules are made to be placed behind a wall outlet or light switch. Crownstone can offer an even more complete range of products by developing smart wall switches and smart wall dimmers.
In this product, it's essential that no neutral line is necessary for operation since the switch boxes in older homes are only equipped with a live and switching wire.

1.3 Assignment and objective

The final goal of this internship is to realise a prototype of a smart wall switch and dimmer.
Initially, the prototype will make use of an nRF52832 microcontroller. This is a Bluetooth 5.2 System-on-Chip (SoC) with support for Bluetooth Low Energy (BLE) and Bluetooth mesh.
In a later prototype an nRF5340 or nRF9160 microcontroller will be used. Where nRF5340 has the same features as the microcontroller used in the first prototype, but has a dual-core and supports Zigbee and Thread. The nRF9160 is a low power System-in-Package (SiP) with an integrated LTE-M/NB-IoT modem and GPS.

2 Research and analysis

As part of this internship, short research is conducted to orient various possible solutions for the design. First, the research will focus on two techniques used for dimming. After that, ways to power the circuit will be discussed.

2.1 Goal

The aim of this research is to find a suitable solution for realising a dimmer circuit that can operate in a 2-wire configuration. This means no neutral wire is needed for using the dimmer.

Main question and sub-questions

How can a dimmer/switch be powered without the use of a neutral wire?

What techniques are used for dimming AC signals?
Is stored energy suitable for powering a dimmer/switch?
Can the dimmer powered of energy harvested from the environment?

2.2 Dimming

The most conventional method of AC mains dimming is phase-cut dimming. In this technique, a part of the AC wave is cut off (figure 1).
In phase-cut dimming, there are two possible implementations leading-edge or forward phase, which cuts off in the first part of the half-cycle (figure 1a). Since the point of turning on varies in a leading-edge dimmer, the AC signal will get a steep rising edge [12]. Dimming capacitive loads, such as LED drivers, causes large current spikes.
Trailing edge or reverse phase dimming cuts off in the second part of the half-cycle (figure 1b). The load always turns on at the zero-crossing of the AC line cycle. This allows the current to rise with the mains voltage naturally. This type of dimming is more effective on capacitive loads since there is no fast rise in the AC signal.

(a) Leading edge (b) Trailing edge

Figure 1: Types of dimming [1]

Type	Description	Possible components
Leading edge	Switching on of the AC power is delayed, the first part of the period is cut off. Circuit realatively easy to realise. Most suitable for inductive loads: transformers and motors	SCR: triac, thyristor Transistor: IGBT, MOSFET
Trailing edge	Switching off the AC power early, the second part of the period is cut off Most suitable for capacitive or resistive loads: LED lighting, TL en conventional bulbs	Transistor: IGBT, MOSFET

Table 1: Comparison of dimming techniques

2.3 Powering the device

As section 3.1 shows, the output switching part of the dimmer will consist of two main components: a relay and a dimmer. When the load is turned off, a voltage will drop over the relay and dimmer. This voltage drop can be used to power the microcontroller. Figure 2 shows how the dimmer and power supply would be inserted in the circuit, where the wire to the lamp acts as the neutral wire to the device.

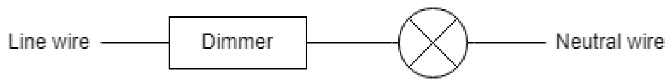


Figure 2: Schematic representation of the device placement

However, when the load is switched on, the voltage drop across the relay will disappear, and there won't be any power for the microcontroller or for switching the relay. The following sections will discuss the possibilities for powering the microcontroller for when the load is switched on.

2.3.1 Storing energy

One possible solution would be using (rechargeable) batteries or a supercapacitor to power the device when the load is switched on. The battery needs to be able to power the microcontroller for a given amount of time and switch back the relay to turn off the load.
According to the datasheet for the ADW1212 [15], the relay used in the Crownstone Built-in devices, the voltage and current needed to switch are 12V and 33,3mA. For switching, the coil needs to be powered for 15 milliseconds. This results in a total charge of approximately 500µC (equation (1)).

$$E = I \times U \times t, \quad E = Q \times U, \quad Q_{set/reset} = 33.3\text{mA} \times 15\text{ms} \approx 500\text{µC} \tag{1}$$

Radio transmitting	8.9mA
Radio receiving	6.7mA
Radio standby	3.4mA
Standby	1.9mA
Idle	2.0µA

Table 2: Power consumed by nRF52832 [14]

The current usage of the nRF52832 SoC strongly depends on the usage of the radio (table 2), according to Nordic's power profiler [13]. If the SoC has BLE events in an interval of 25ms with every event using about 17µC, the total charge needed for one hour of operation would be $17\mu C \times 40 \times 3600 = 2.45C$.

Supercapacitor

Using an Eaton TV-series supercapacitor [7] with a capacitance of 6F at 3V holds a charge of 18C. This could, in theory, power the microcontroller for $18C/2.45C \approx 7$ hours.

However, in practice, this doesn't hold up since there are losses. First of all the supercapacitor used in the example above has a nominal leakage current of 13µA, this means the capacitor will slowly discharge itself in $\frac{7.5\text{mW h}}{3.0\text{V}\times 13\mu\text{A}} \approx 192$ hours.

(a) Battery

(b) Supercapacitor

Figure 3: Discharge curves at a constant current [8]

Secondly, the voltage across the capacitor decreases linearly (figure 3b) unlike a battery, where the voltage remains almost the same for most of the time (figure 3a). As a result of the voltage decreasing, not all the energy stored in the capacitor can be used.
According to Nordic's nRF52832 product specifications [14], the microcontroller can operate on a supply voltage range of 1.7V-3.6V. With the voltage of the supercapacitor [7] linearly decreasing, only about $\frac{1.7V}{3.0V} \times 100\% \approx 56\%$ of the energy stored in the capacitor can be used by the microcontroller.

Rechargeable battery

A wide variety of rechargeable batteries are available, the most common types being Nickel-Metal hydride (NiMH) and Lithium-polymer (LiPo).

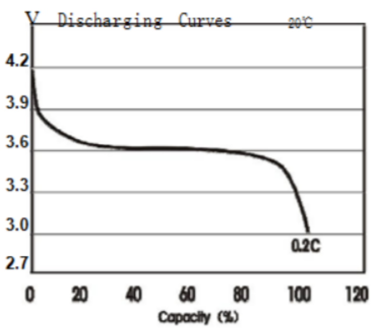


Figure 4: The discharge curve of a NiMH cell [20]

Both NiMH and LiPo batteries have similar discharge curves (figure 4), where they're usable to

about 90% of their capacity. After this point, the voltage of the cells drops quickly.
The main disadvantage of these cells is that they require specialized charging circuits.

Comparison

As shown in table 3, the charge times and capacity of the three solutions are quite different. The best fit for this application would be a LiPo cell, since this type of battery can power the circuit relatively long and is able to charge in a shorter time.

	NiMH [20]	Supercap [7]	LiPo [19]
Self discharge	up to 3%/month	13µA leakage	5-10%/month
Max. Charge current	8mA	7.4A	75mA
Charge time	min. 10 hours	min. 2 seconds	min. 1 hour
Lifespan	700-1000 cycles	about 500.000 cycles	500-1000 cycles
Operating temperature	-20 - 35 °C	-40 - 60 °C	0 - 35 °C
Capacity	288mWh	7.5mWh	550mWh
Volume	⌀11 x 22mm	⌀16 x 24mm	24 x 10 x 5mm

Table 3: Comparison of a NiMH cell, a supercapacitor and a LiPo battery

2.3.2 Energy harvesting

An alternative way to power the microcontroller would be to harvest power from the dimmer's environment. A few different techniques for harvesting power will be described in the following sections.

Capacitive energy harvesting

The CapHarvester, as described in the article, [9] is a device that clamps onto a low voltage domestic power cable and harvests power without current flow.
The system consists of four main components: capacitive electrodes, a diode bridge rectifier, a storage capacitor and a MOSFET for high side switching.
The charging time and thus the average power of the system strongly depends on the placement of the CapHarvester (table 4), where the coupling to earth ground is most of interest.
Besides the placement, the average power is also influenced by the capacitive coupling of cable types (length, different gauges and outer shielding).

Location	Surface	Charge Time (s)	Average Power (µW)
Ground floor of cement office building	Tile floor	277	0.95
Fifth floor of cement office building	Carpet	731	0.36
Second floor of wooden house	Carpet	1308	0.20
Outdoors	Concrete	242	1.09
Wooden Stud	Wood	780	0.34
Wooden Attic	Wood	2356	0.11
Wooden floor	Wood	2500	0.11
Residential basement	Carpet	653	0.40
Table in residential basement	Wood	617	0.43
Residential garage	Epoxy coating	267	0.99
Fifth floor of a cement lab rotary building	Epoxy coating	467	0.57

Table 4: Charge time and average power harvested using CapHarvester in various locations in the US (110V/60Hz) [9]

The main problem when using the CapHarvester is that when it's suspended in free air or placed on drywall, the device won't work due to the poor coupling to earth ground. This makes this technique less suitable for smart switches, which are commonly placed in walls.

Inductive energy harvesting

This type of energy harvesting relies on the current flow through a conductor, which produces a magnetic field around the conductor, the same technique used in a transformer.
The electromagnetic harvesting device described in the article [21] uses a current transformer with a winding ratio of 1:1200 (figure 5, figure 6), where the single turn is the live wire carrying the current to the load.

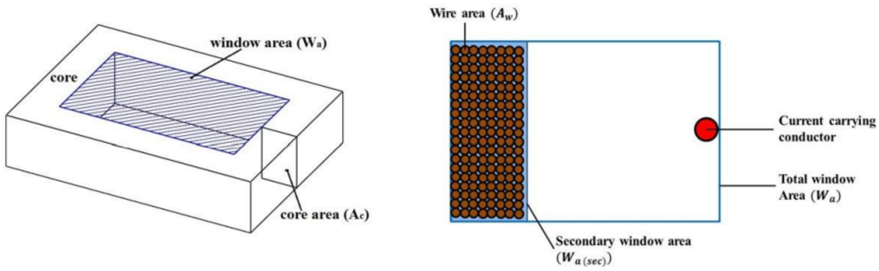


Figure 5: Current transformer used for electromagnetic harvesting [21]

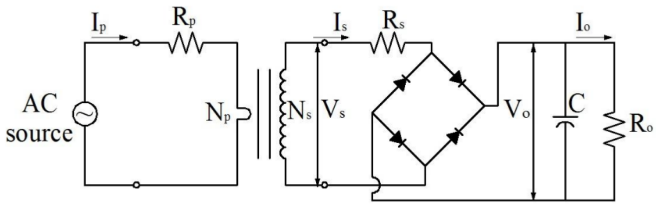


Figure 6: Circuit diagram of an inductive harvesting device [21]

Harvesting power from the magnetic field caused by the current flow through the conductor would need a For harvesting power from the magnetic field around the conductors inside walls, a significant current needs to flow thought the conductor (> 1A). This requires a heavy load with a minimum power draw of about 230 Watt. In most indoor lighting applications the power doesn't exceed 100 Watt, this results in not enough energy in the magnetic field.

2.3.3 Creating a voltage drop

A third possible solution would be to interrupt the power to the load for short periods of time. Doing this creates a voltage drop which can be used to power the microcontroller.

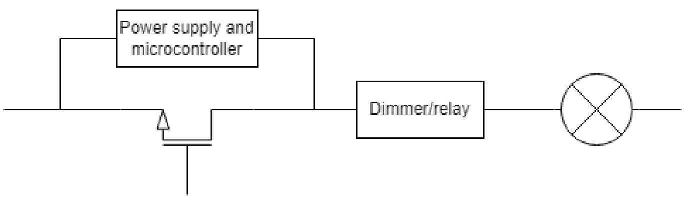


Figure 7: Schematic representation of the power supply and dimmer/relay

A possible implementation for interrupting the power would be adding a MOSFET [10] or IGBT [12] in series with the AC line as schematically shown in figure 7.
In this setup, when the MOSFET is on, the current will flow through the dimmer and power the load. When the MOSFET is turned off, a voltage drop will be available for the power supply.

2.4 Conclusion

Storing energy, as discussed in section 2.3.1 isn't a realistic solution for powering the dimmer. Mainly because of the limited time that the light can stay on, but also because of the high cost (supercapacitor) or the charge times (NiMH/LiPo) and the limited life span (NiMH/LiPo).

Harvesting energy from the environment is a technique that is more suited to low power applications. For instance remote switches, which only use the SoCs radio when a switch event occurs. Unlike dimmers, which constantly need sufficient power. Another disadvantage of energy harvesting is it being voluminous.

The most effective solution for powering the dimmer and microcontroller is creating a voltage drop, as described in section 2.3.3. This technique allows for two-wire operation of the dimmer and doesn't limit the time that the lamp can stay on.

3 Definition phase

3.1 Program of requirements

This section will discuss the system's requirements. All requirements are categorized using the MoSCoW method (table 5).

Abbreviation	**Meaning**	
MH	Must Have	This requirement needs to be developed to ensure proper functioning of the product.
SH	Should Have	Not necessary, but meeting this requirement is desirable.
CH	Could Have	Not necessary, only when there is time.
WH	Won't Have	Not needed.

Table 5: MoSCoW abbreviations

3.1.1 Power supply

REQ-1.1[MH]	The system shall operate on a voltage between 207V and 253V RMS.
REQ-1.2[MH]	The system shall be able to operate without the need of a neutral wire (2-wire).
REQ-1.3[SH]	The system shall be able to operate with the use of a neutral wire (3-wire).
REQ-1.4[MH]	Zero-crossings of the AC line shall be detected.

3.1.2 Dimmer and switch

REQ-2.1[MH]	The system shall have a leading-edge dimming mode.
REQ-2.2[MH]	The system shall have a trailing-edge dimming mode.
REQ-2.3[MH]	The system shall be able to continuously dim loads up to 100 W
REQ-2.4[MH]	The system shall be able to dim all types of dimmable bulbs.
REQ-2.5[MH]	The system will be controlled via Bluetooth.
REQ-2.6[SH]	The system will be controlled via a rotary knob.
REQ-3.1[CH]	The product will have a relay to switch high power loads.
REQ-3.2[CH]	The relay shall be switched on a zero-crossing of the AC power.

3.1.3 Microcontroller

REQ-4.1[MH]	The system shall use a certified nRF52832 module.
REQ-4.2[MH]	The SoC module shall have an integrated antenna.
REQ-4.3[MH]	The SoC shall run Crownstone's Bluenet firmware.
REQ-4.4[MH]	The system shall have an UART connection for debugging.
REQ-4.5[MH]	The system shall be programmed via the SWD connection.

3.1.4 Safety requirements

REQ-5.1[MH]	The product will shut down when the temperature gets too high.
REQ-5.2[SH]	The product shall have overcurrent protection.
REQ-5.3[SH]	The product shall have input surge protection.
REQ-5.4[SH]	The product will be protected against wrong connections.
REQ-5.5[MH]	The product will discharge after disconnecting AC power.

3.1.5 Non-Functional requirements

REQNF-1[MH]	The connectors shall be suitable for solid core 2.5mm^2 cables.
REQNF-2[MH]	The connectors shall be suitable for solid core 1.5mm^2 cables.
REQNF-3[MH]	The PCB shall fit within the 3D model of the housing.
REQNF-4[SH]	The bottom side of the PCB shall have a debug connector.

REQNF-5[**MH**] The connectors will be VDE certified.
REQNF-6[**MH**] The product will not produce any audible noise.

4 Architecture phase

This chapter will describe the structure of the system. The architecture will describe all subsystems and their connections.

4.1 Context diagram

The context diagram in figure 8 shows how the external sources interact with the system.
The diagram consists of three terminators and the general function of the system. The user can provide a dimmer value to the system and vice versa. The system connects to the mains power via the line wire. The dimmer output wire doubles as a neutral wire to the system since it connects to the neutral wire via the lamp.

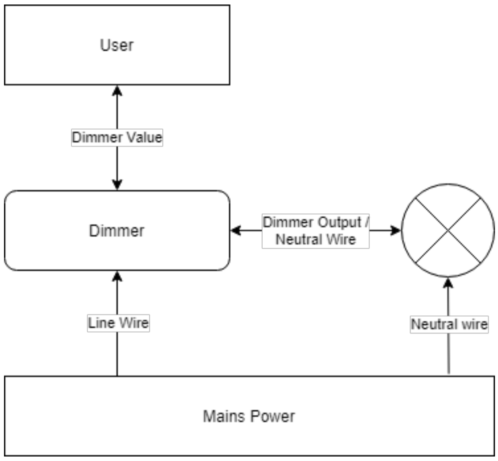


Figure 8: Context diagram

4.2 Architecture Interconnect Diagram

The architecture interconnect diagram (figure 9) gives a more detailed overview of the system. This diagram shows the connections between the three subsystems (Power supply, Microcontroller and Dimmer) and their external connections as shown in figure 8.

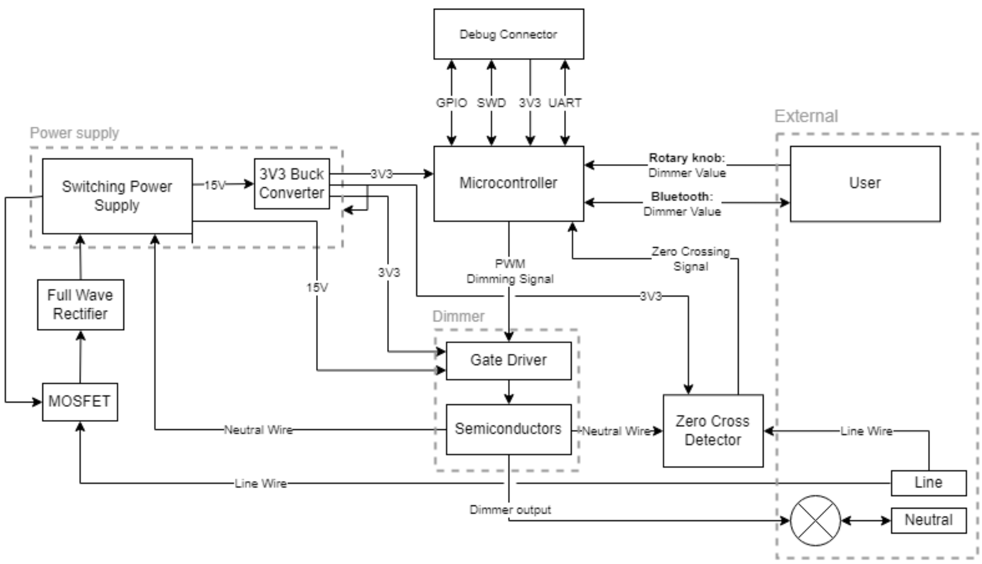


Figure 9: Architecture interconnect diagram

4.3 Subsystems

The system consists of three subsystems, the following sections will briefly describe these subsystems, and the data flows between them.

4.3.1 Power supply

The power supply contains four parts: a half-wave rectifier, DC to DC power converters and zero-crossing detection.
This subsystem provides power at the right voltage for the gate driver and microcontroller. The zero-crossing system will supply a square wave signal to the microcontroller.

4.3.2 Microcontroller

The microcontroller is part of the SoC, which handles Bluetooth communication and ensures that all subsystems are connected. It receives the zero-crossing detection signal from the power supply, detects the use of the rotary knob and sends a PWM signal to the dimmer system.
External connections to the microcontroller for debug purposes are UART, Serial Wire Debug, four GPIO pins and the ability to power the microcontroller from an external power source.

4.3.3 Dimmer

The dimmer generates the phase-cut output signal from a PWM signal derived from the microcontroller.
This subsystem consists of two semiconductors for phase cutting the output signal and a gate driver to drive the semiconductors.

4.4 Traceability of requirements

The Requirements traceability matrix shows which subsystem is responsible for a requirement.

	Power supply	**Microcontroller**	**Dimmer**
REQ-1.1	✓		✓
REQ-1.2	✓		✓
REQ-1.3	✓		
REQ-1.4	✓	✓	
REQ-2.1		✓	✓
REQ-2.2		✓	✓
REQ-2.3	✓		✓
REQ-2.4			✓
REQ-2.5		✓	
REQ-2.6		✓	
REQ-3.1	1.		
REQ-3.2		✓	
REQ-4.1		✓	
REQ-4.2		✓	
REQ-4.3		✓	
REQ-4.4		✓	
REQ-4.5		✓	
REQ-5.1	✓		✓
REQ-5.2	✓		
REQ-5.3	✓		
REQ-5.4	✓		✓
REQ-5.5	✓		
NFREQ-1	✓		
NFREQ-2	✓		

NFREQ-3	✓	✓	✓
NFREQ-4	✓		
NFREQ-5	✓		✓
NFREQ-6	✓	✓	✓

Table 6: Requirements traceability matrix

4.5 Data dictionary

The data dictionary shows the connections as displayed in the architecture interconnect diagram (figure 9), table 7 shows a description of the flow, the unit and range.

Data flow	**Description**	**Unit**	**Range**
Power supply:			
Zero-crossing signal	High-low transitioning signal	Volts	0 - 3.3
Power input	Mains AC power input	Volts (RMS)	207 - 253
Microcontroller:			
Dimmer value: knob			0 - 100%
Dimmer value: Bluetooth			0 - 100%
Dimmer:			
PWM dimming signal	Signal from the microcontroller to the dimmer	Duty cycle	0 - 100%
Dimmer output	Phase cut AC power from the dimmer to the light	Duty cycle	0 - 100%
Debug connector:			
UART	Receive, Transmit	Baud	115200
SWD	Clock, I/O	-	-
GPIO	General purpose I/O for debugging	-	-
3V3, GND	External MCU 3V3 power input	Volts	3.0 - 3.6

Table 7: Data dictionary

5 Design phase

To realise the architecture described in section 4 This chapter describes all hardware in the subsystems in detail. The schematics can be found in appendix A and appendix B.

5.1 Power supply

The power supply will consist of three stages. The first stage rectifies the AC line voltage, the second stage converts the rectified voltage to 15V DC for driving the IGBTs and creates the zero-crossing signal. The last stage converts the 15V DC to 3.3V DC to supply the SoC.

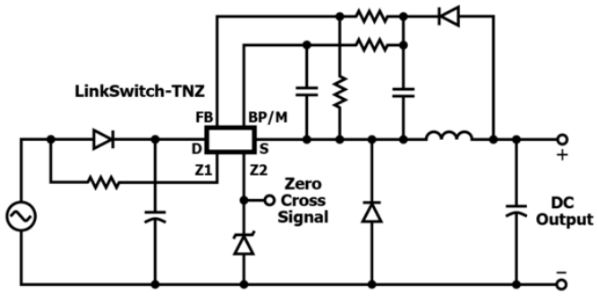


Figure 10: A simplified schematic of a buck converter using a LinkSwitch-TNZ device. [18]

5.1.1 Input stage

As shown in the schematic in A, the input power is half-wave rectified by diode D2. C1 is a bulk capacitor that flattens the rectified AC voltage.
Varistor VAR1 provides input surge protection.

5.1.2 Input DC/DC converter using LNK3302

For converting the AC line voltage to 15 VDC, an off-line switching regulator is used. In this category, there are many components to choose from. The LinkSwitch-TNZ series of off-line switchers is selected because it combines a high-voltage power MOSFET switch, a power supply controller, and a zero-crossing detector in a single device. Which is ideal for this application since it reduces the number of external components needed for the power supply and zero-crossing circuit.
Based on the typical output current for a non-isolated buck configuration, given in the datasheet [18], LNK33x2D is chosen. This device can supply up to 80mA of current in continuous conduction mode. Two versions of this IC are available, LNK3302D and LNK3312D, the difference being the ability to discharge an X-capacitor. Since this will not be necessary, LNK3302D is chosen.

The LinkSwitch device is configured as a high-side buck converter (figure 10). For calculating the values of external passive components needed for operation of the LinkSwitch IC, PI Expert's spreadsheet is used (appendix C). This is a hardware design tool from Power Integrations, manufacturer of the LinkSwitch-TNZ ICs.

The most important input parameters for the design tool are:

- Input voltage of 230V RMS ±10% at a frequency of 50 Hz
- Output voltage of 15V DC
- Maximum output current of 60mA
- Forward voltage drop of the freewheeling diode (D7)

The most useful output parameters of the design tool are:

- Input capacitor value (C1)
- Inductor value (L1)
- Feedback resistor value (R2)

- Feedback capacitor value (C3)
- Bypass pin resistor value (R3)
- Bias resistor value (R1)

5.1.3 Zero-crossing circuit

The microcontroller should switch on the semiconductors when the AC signal crosses zero. For this, the microcontroller needs a zero-crossing signal. LNK3302D can provide this zero-crossing signal, which toggles each time the AC line crosses zero volts.
For the zero-crossing signal to be read by the microcontroller, it needs to be within the operating voltage range of the chip. N-MOSFET Q1 converts the zero-crossing signal to the correct logic level for the microcontroller.
C4 and R6 form a low pass filter for the zero-crossing output of the LinkSwitch IC. The signal toggles every half AC line cycle, so the frequency should be 50 Hz, the same as that of the AC line. R7 is the pulldown resistor on the gate of Q1. D3 and D4 form the sensing circuit with R4 in series with zenerdiode D6.

5.1.4 LDO

To supply a steady 3.3V to the SoC module, an Low Dropout Regulator (LDO) is added. According to the datasheet of the module [2], the maximum current consumption of the module is 9.6mA.
For this purpose, the LP2985-N with a fixed output voltage of 3.3V is chosen, mainly because of the relatively high DC input voltage of 16,V [22] and it needs a minimal amount of external components.
This design will not use the shutdown function of the regulator, the ON/OFF will be tied to $\mathrm{V_{IN}}$ to always keep the regulator in normal operation mode.
Capacitor C7 is a noise bypass capacitor, allowing a low-noise output of the LDO [22].
The power loss of the device is given by equation (2), to calculate the efficiency η of the LDO $\frac{P_{IN}-P_{LOSS}}{P_{IN}}$ is used.

$$P_{LOSS} = (V_{IN} - 3.3\text{V}) \times I_{OUT} + V_{IN} \times I_Q \approx (15\text{V} - 3.3\text{V}) \times 15\text{mA} \approx 176\text{mW} \tag{2}$$

When the LDO is in operation, $I_{OUT} \gg I_Q$. Therefore I_Q is negligible, which allows to further reduce the efficiency to equation (3).

$$\eta = \frac{V_{OUT}}{V_{IN}} = \frac{3.3\text{V}}{15\text{V}} = 22\% \tag{3}$$

5.2 Power supply (2nd iteration)

The first version of the power supply as described in section 5.1, had some limitations. The most significant limiting factors of the circuit are the availability of certain components and the high power dissipation of the LDO.
This second version of the power supply will have the same output specifications but will focus more on the availability of the used components. The schematics for this version can be found in appendix B.
The power supply is made up of four subsystems, the input stage which rectifies the AC line voltage, two switching voltage regulators and a zero-crossing circuit.

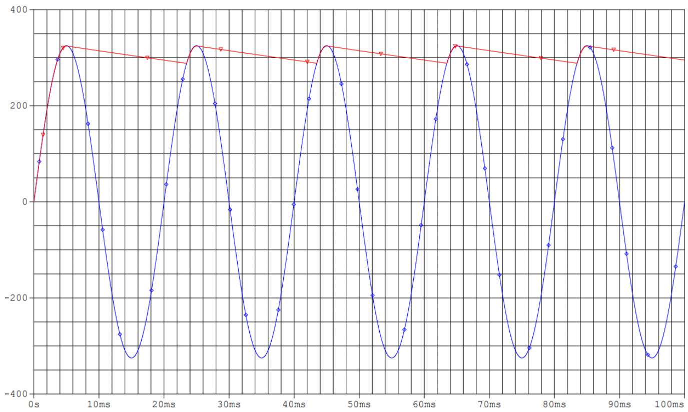


Figure 11: AC line voltage (blue) and half rectified, flattened signal (red)

5.2.1 Input stage

As shown in the schematic in B, the input power is half-wave rectified by diode D2. C1 is a bulk capacitor that flattens the rectified AC voltage (figure 11).
Varistor VAR1 provides input surge protection. Fuse F1 is for safety protection against circuit failure.

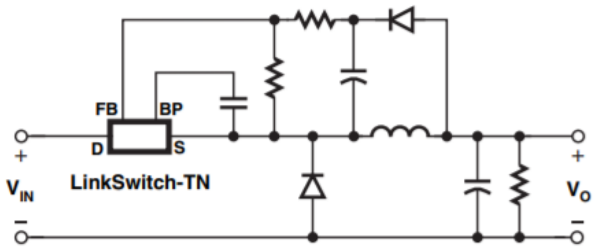


Figure 12: A simplified schematic of a buck converter using a LinkSwitch-TN device [17]

Voltage drop circuit

As described in subsubsection 2.3.3, a voltage drop will be used to power the circuit. To create this voltage drop, a MOSFET is added in series with the input AC line.
Initially, the MOSFET is off. Creating a voltage drop for the power supply.
2.todo, aanvullen

5.2.2 Input DC/DC converter using LNK302

LinkSwitch-TN devices integrate a 700V power MOSFET and a power supply controller, using simple on/off controlling for regulating the output voltage. LinkSwitch-TN devices are available in four types, with different output power capabilities. According to the datasheet [17], LNK302 can deliver up to 63mA of output current, which suits the needs of the circuit.

In this design, LNK302 is configured as a buck converter with direct feedback (figure 12). For calculating the values of the external components needed, PI Expert's spreadsheet is used. The complete spreadsheet can be found in appendix D.
The most important input parameters for the design tool are:

- Input voltage of 230VRMS $\pm$ 10% at a frequency of 50 Hertz
- Output voltage of 15VDC
- Target output voltage ripple of 100mV_{pk}
- Maximum output current of 60mA
- Forward voltage drop of the freewheeling diode (D4)

The most useful output parameters of the design tool are:

- Input capacitor value (C1)
- Inductor value (L1)
- Feedback resistor value (R2)
- Feedback capacitor value (C2)
- Bias resistor value (R1)

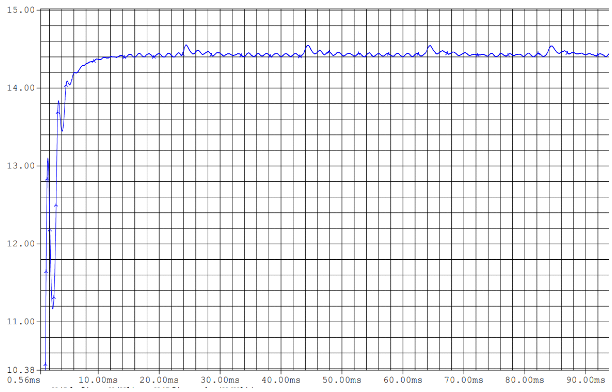


Figure 13: Output voltage of the LNK302 buck converter

As shown in figure 13, the output voltage ripple is about 14.51V − 14.42V = 90mV, which meets the requirements.

5.2.3 Zero-crossing circuit

This new simplified zero-crossing circuit consists of a voltage divider and an opamp used as a comparator. This circuit is chosen, because of its low cost and high availability of the components. A rail-to-rail single supply opamp is used to be able to create an output signal between 0 and 3.3V. The voltage divider attenuates the AC line signal from 253VRMS $\times \sqrt{2} \approx 357\mathrm{V_{pk}}$ to a voltage within the range of the comparator (equation (4)). The current from the AC line leaking through resistors R5 and R6 and the power dissipated by the resistors is given by equation (5).

$$V_{comparator} = V_{in}\frac{R5}{R5+R6} = 357\mathrm{V_{pk}}\frac{82\mathrm{k\Omega}}{10\mathrm{M\Omega}+82\mathrm{k\Omega}} \approx 2.9\mathrm{V_{pk}} \tag{4}$$

$$I_{ACleak} = \frac{340}{10\mathrm{M\Omega}+82\mathrm{k\Omega}} \approx 34\mathrm{\mu A}, \qquad P_{resistors} = (34\mathrm{\mu A})^2 \times (10\mathrm{M\Omega}+82\mathrm{k\Omega}) \approx 12\mathrm{mW} \tag{5}$$

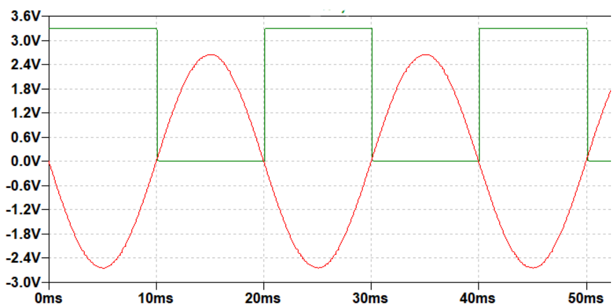


Figure 14: Attenuated AC line (red) and zero-crossing signal (green)

The zero-crossing signal is a square wave, which inverts every half AC-line cycle as shown in the simulation results (figure 14).

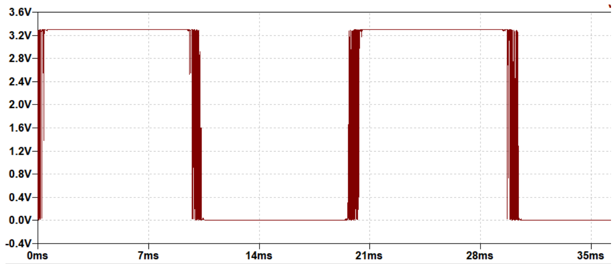


Figure 15: Bouncing output signal caused by noise

In the LT-Spice simulation, a perfect sine wave is used to simulate the detection of zero-crossings. However, the mains voltage isn't an ideal sine wave because of the noise present on the power grid. This noise will result in the opamp output bouncing around the zero-crossing (figure 15). This bouncing signal will first be filtered by the firmware running on the MCU to detect a zero-crossing. Another option would be hardware filtering the signal, but the firmware option is preferred due to its flexibility.

5.2.4 3.3V DC/DC converter

To create a stable 3.3V for the SoC module in an efficient way, a second DC/DC step-down converter is used. LT1934-1 is chosen for its wide input voltage range of 3.2V - 32V [11], as well as its output current of 60mA and lastly its availability. Since the maximum power drawn by the SoC is 9.6mA, this will fit well within the specifications of the DC/DC converter.

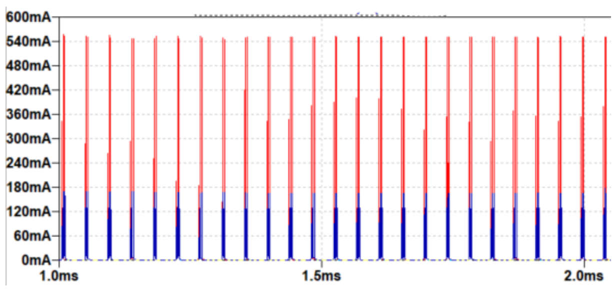


Figure 16: Plot of the input current of the buck converter at the device (red) after the capacitor (blue)

Buck converters draw current from the input in short pulses with fast rise and fall times, as shown in figure 16. To reduce the current drawn from the output of the LNK302 power supply, input capacitor C5 of 1µF is added to the input of the device. [11]
At an output current of 45mA, the manufacturer recommends a minimal inductor value of 100µH.

$$\mathrm{C_{OUT}} > 50 \times \mathrm{L} \times (\mathrm{I_{LIM}}/\mathrm{V_{OUT}})^2 \tag{6}$$

The minimum output capacitance can be calculated using equation (6) The current limit of the switch in the LT1934-1 is 120mA, this solves for $C_{OUT} > 6.6\mu F$. Capacitor C7 is added to further reduce the output voltage ripple caused by the feedback comparator.

$$V_{OUT} = 1.25\mathrm{V}(1 + R3/R4) = 1.25\mathrm{V}(1 + 1\mathrm{M}\Omega/620\mathrm{k}\Omega) = 3.27\mathrm{V} \tag{7}$$

The output voltage is set by a voltage divider of R3 and R4 on the feedback pin (equation (7)). D6 is used as a flyback diode for the inductor. Here, a CMDSH2 Schottky diode is chosen for its reverse voltage rating of 30V, forward current rating of 200mA [5]and low forward voltage drop, resulting in higher efficiency of the buck converter due to less power dissipation in the diode.

Finally, D5 and C6 create a boost voltage higher than the input voltage. This voltage is used to drive the internal NPN switch of the device.

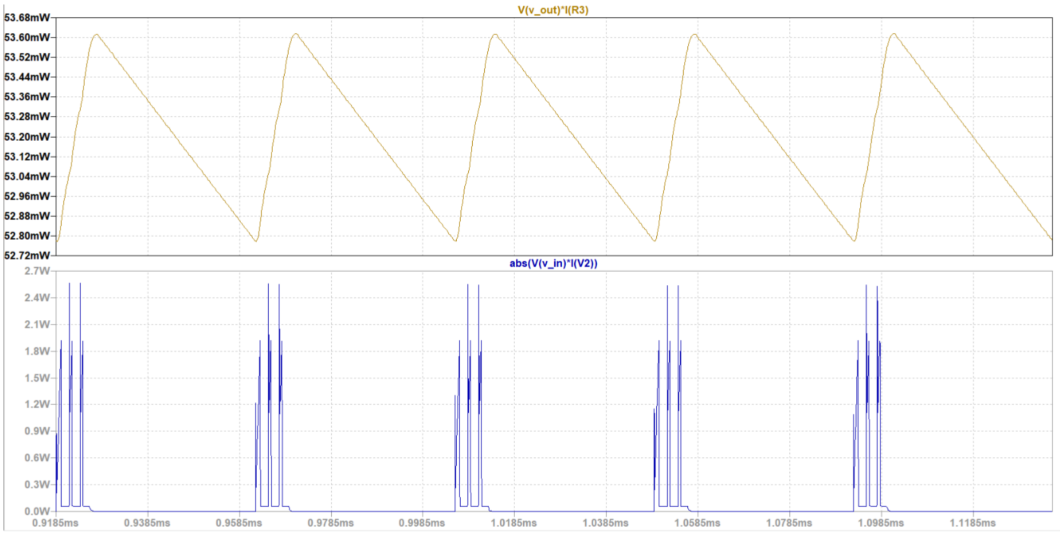


Figure 17: Plot of 5 periods of the output (top) and input (bottom) power

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{53.2\text{mW}}{73.8\text{mW}} = 72\% \tag{8}$$

The efficiency of the step-down converter is given by equation (8), which uses the average in and output current computed by LTspice [6].

5.3 Microcontroller

To realize the microcontroller subsystem, a Nordic Semiconductor BLE SoC was chosen. This is a highly integrated SoC that contains a 2.4 GHz transceiver, a 32-bit ARM® Cortex™-M4F CPU, a 512 kB flash memory, 64 kB RAM as well as analog and digital peripherals (figure 18). Crownstone already uses the nRF52832 SoC which is running Bluenet, the in-house firmware for all Crownstone hardware.

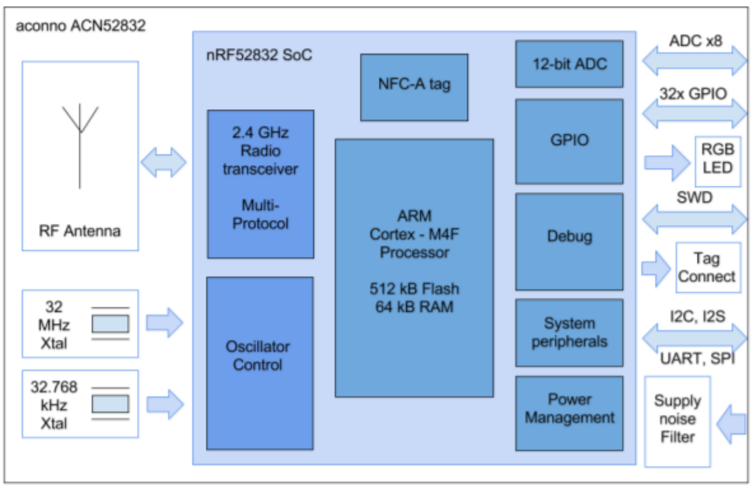


Figure 18: Block diagram of the ACN52832 module Source: [2]

For the dimmer prototype, a fully integrated module featuring the nRF52832 SoC will be used: Aconno's ACN52832 [2]. This module integrates Nordic's nRF52832 BLE SoC, the accompanying PCB antenna with RF matching circuit, power supply decoupling capacitors, 32 MHz and 32.768 kHz crystals and load capacitors. This module also includes an RGB LED for optical feedback.
For programming the MCU and debugging software, ARM's 2-pin Serial Wire Debug (SWD) port and a UART connection are used. To be able to easily connect these pins, a debug connector is added to the board.

5.4 Dimmer

5.4.1 Selecting an IGBT

3.

5.4.2 Driving the IGBTs

4.

5.5 Connectors

Power connector

As stated in requirements NF-1 and NF-2 , since connectors need to fit solid core wires of multiple gauges, screw terminal blocks were chosen for making the power connections.
The power screw terminals must meet the following requirements:

- Minimal voltage rating of 253V RMS, *REQ-1.1*
- Minimal current rating of 10A, *REQ-2.3, REQ-3.1*
- Suitable for both 1.5mm^2 and 2.5mm^2 cables, *NF-1* , *NF-2*
- VDE safety certification, *NFREQ-5*
- 4 connections, *REQ-1.2, REQ-1.3*

A Phoenix Contact MKDSN 2.5/4 BK screw terminal is chosen based on these requirements. This component is rated for a nominal current of 16A, a nominal voltage of 400V, allows the connection of a 0.2mm^2 to 2.5mm^2 conductor and is VDE approved [16].
The power connector will have the following connections:

- Live
- Live
- Neutral
- Switched output

Debug connector

For compatibility, the debug connector will have the same pinout and PCB footprint as the debug connector found on the Crownstone Built-In devices. The connector itself is a surface mount ten pin, two-row header with a 2.54mm pitch [3].
The debug connector will have the following connections:

- Supply power: GND, 3V3
- UART: RXD, TXD
- SWD: Clock, IO
- Four GPIO pins

5.6 Interface

A potentiometer, as found on most dimmers, isn't suitable for controlling the dimmer via both Bluetooth and a knob on the device. For this reason, a quadrature output rotary encoder is chosen.

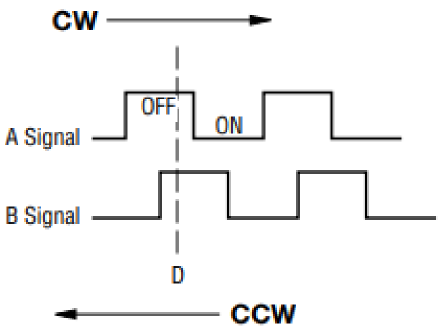


Figure 19: Quadrature output of the rotary encoder [4]

A rotary encoder's main advantage is its ability to rotate left and right unlimited, as well as it having a push switch.
The output signal of the rotary encoder consists of two square waves which are 90 degrees out of phase figure 19. This way the firmware on the microcontroller can detect a clockwise and counterclockwise rotation of the knob. If, for example, signal A leads signal B, the rotation is clockwise. For using the encoder as an input to the microcontroller, the common connection is connected to ground and the two switch outputs are pulled high to 3.3V via 10kΩ resistors. Between the output of the encoder and the microcontroller, an RC filter is added to filter the bouncing signal.

6 Test Phase

This section describes all unit test procedures and criteria and the results of the unit tests.

6.1 Power supply

The power supply unit test is split up into four tests. In unit tests 1.1 and 1.2, the DC/DC converters will be tested individually. Unit tests 1.3 and 1.4 test both buck converters as a whole. Unit test 1.5 will test only the zero-crossing circuit, unit test 1.6 tests the zero-crossing circuit as part of the whole system.

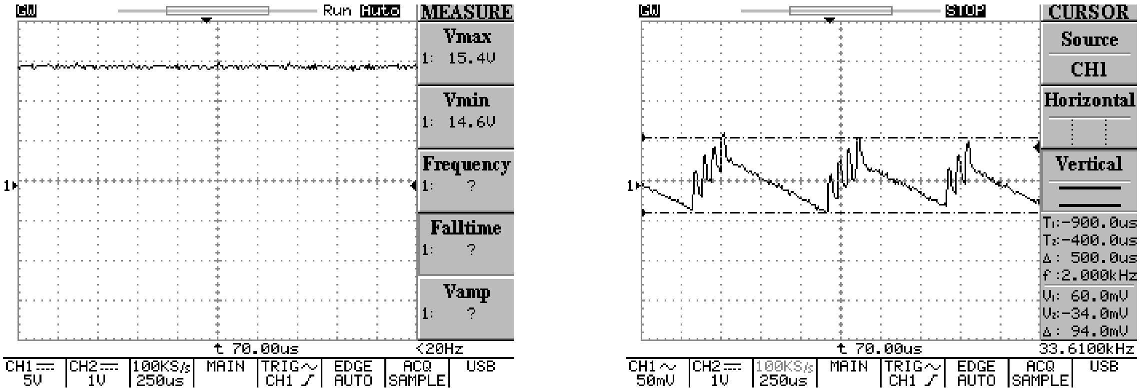
6.1.1 Unit test 1.1, 15V buck converter test

According to the datasheet [17], LNK302 is rated for a supply voltage as low as 50V DC. This lower voltage allows for safer testing of the circuit in a low voltage DC test.
In this test, two load resistors are used to simulate different current draws from the buck converter.

Tested requirements	**REQ-1.2** The system shall be able to operate without the need of a neutral wire (2-wire). **REQ-5.1** The product will shut down when the temperature gets too high. **REQ-5.2** The product shall have overcurrent protection. **REQNF-1** The connectors shall be suitable for solid core 2.5mm^2 cables. **REQNF-2** The connectors shall be suitable for solid core 1.5mm^2 cables.
Required materials	Oscilloscope Bench DC power supply Multimeter Load resistors
Test criteria	The system will pass the test when: • The output voltage of the buck converter is between 14.5V and 15.5V DC • The maximum output voltage ripple is 100mV
Test procedure	Steps to test the unit: 1. Set the DC power supply to 60V DC by using the serial mode, set the current limit to 50mA 2. Connect the bench power supply to the unit 3. Set the oscilloscope to DC coupling, 5V/div, 250µs/div 4. Connect a load resistor of 1kΩ to the output of the unit 5. Connect the oscilloscope to the output of the system 6. Switch on the bench power supply 7. Measure the DC output voltage of the system 8. Set the oscilloscope to AC coupling, 100mV/div, 250µs/div 9. Connect the oscilloscope to the output of the system 10. Measure the output voltage ripple of the system 11. Repeat the test with a load resistor of 560Ω

Table 8: Unit test 1.1, 15V buck converter test

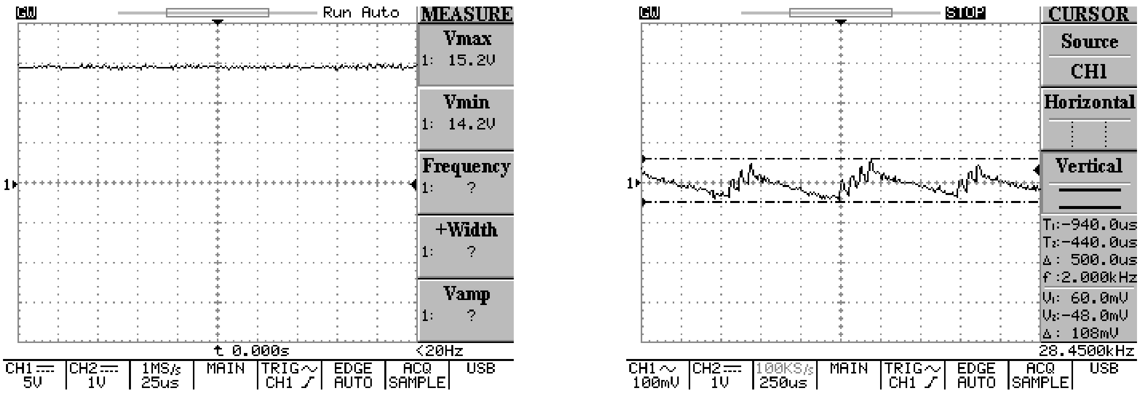
6.1.2 Test results unit test 1.1



(a) DC Coupling (b) AC Coupling

Figure 20: Test results unit test 1.1, 1kΩ load resistor

The 1kΩ load resistor causes a current flow of 15mA at the output of the buck converter. Figure 21a shows the measurement made in step 6 of the test, the DC output voltage of the system. The voltage measured is between 14.6V and 15.4V, which meets the criteria of the test. Figure 21b shows step 8 of the test, the measurement of the output voltage ripple (ΔV). The measured voltage ripple is 94mV, which meets the criteria of the test.



(a) DC Coupling (b) AC Coupling

Figure 21: Test results unit test 1.1, 560Ω load resistor

5.todo, testresultaten lnk302 met 560 ohm load

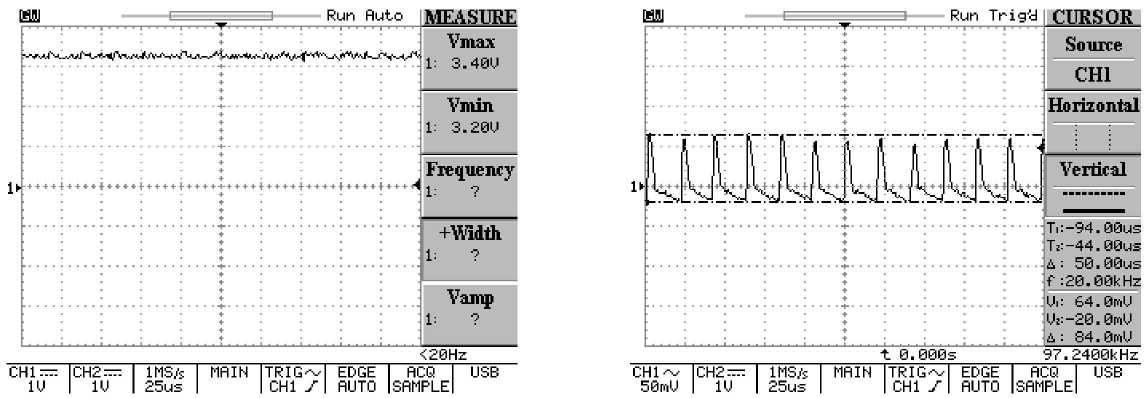
6.1.3 Unit test 1.2, 15V to 3.3V converter test

This unit test will test the second stage of the power supply, the 3.3V output.

Tested requirements	**REQ-1.2** The system shall be able to operate without the need of a neutral wire (2-wire). **REQ-5.1** The product will shut down when the temperature gets too high. **REQ-5.2** The product shall have overcurrent protection. **REQNF-1** The connectors shall be suitable for solid core 2.5mm^2 cables. **REQNF-2** The connectors shall be suitable for solid core 1.5mm^2 cables.
Required materials	Oscilloscope Bench DC power supply Load resistor
Test criteria	The system will pass the test when: • The output voltage of the buck converter is between 3V and 3.3V DC • The maximum output voltage ripple is 100mV$_{pp}$
Test procedure	Steps to test the unit: 1. Set the DC power supply to 15V DC, set the current limit to 50mA 2. Connect the bench power supply to the unit 3. Connect a 200Ω load resistor to the output of the unit 4. Set the oscilloscope to DC coupling, 1V/div, 25µs/div 5. Connect the oscilloscope to the output of the unit 6. Switch on the bench power supply 7. Measure the DC output voltage 8. Set the oscilloscope to AC coupling, 50mV/div, 25µs/div 9. Connect the oscilloscope to the output of the unit 10. Measure the output voltage ripple

Table 9: Unit test 1.2, 15V to 3.3V converter test

6.1.4 Test results unit test 1.2



(a) DC Coupling (b) AC Coupling

Figure 22: Test results unit test 1.2

The 200Ω load resistor causes a current flow of 16.5mA at the output of the buck converter. This is similar to the current the microcontroller will draw.

By AC coupling the measured output, the DC component is filtered out of the signal, allowing for a better view of the voltage ripple. The measured voltage ripple (ΔV) shown in figure 22b is 84mV, which is within the criteria of the test.

6.1.5 Unit test 1.3, low voltage DC test

This unit test will test both the first and second stages of the power supply. For safer testing, this test uses a low voltage DC source.

Tested requirements	
Required materials	Oscilloscope Bench power supply Load resistors
Test criteria	The system will pass the test when: • The output voltage of the first buck converter is between 14.5V and 15.5V DC • The output voltage of the second buck converter is between 3V and 3.3V DC • The maximum output voltage ripple is $100mV_{pp}$
Test procedure	Steps to test the unit: 1. Set the DC power supply to 60V DC by using the serial mode, set the current limit to 50mA 2. Connect the bench power supply to the unit 3. Set the oscilloscope to DC coupling, 5V/div, 250µs/div 4. Connect a load resistor of 1kΩ to the output of the 15V buck converter 5. Connect a load resistor of 200Ω to the output of the 3.3V buck converter 6. Connect the oscilloscope to the output of the 15V buck converter 7. Switch on the bench power supply 8. Measure the DC output voltage of the 15V buck converter 9. Set the oscilloscope to DC coupling, 1V/div, 25µs/div 10. Connect the oscilloscope to the output of the 3.3V buck converter 11. Measure the DC output voltage of the 3.3V buck converter 12. Set the oscilloscope to AC coupling, 100mV/div, 250µs/div 13. Connect the oscilloscope to the output of the 15V buck converter 14. Measure the output voltage ripple of the 15V buck converter 15. Set the oscilloscope to AC coupling, 50mV/div, 25µs/div 16. Connect the oscilloscope to the output of the 3.3V buck converter 17. Measure the output voltage ripple of the 3.3V buck converter

Table 10: Unit test 1.3, low voltage DC test

6.1.6 Test results unit test 1.3

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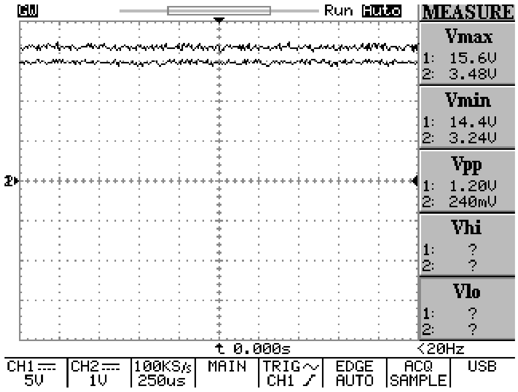
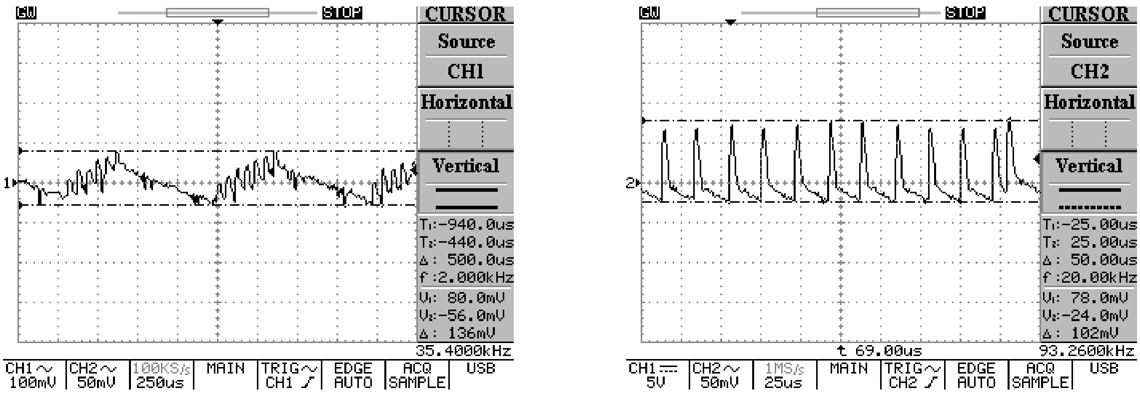


Figure 23: Test results unit test 1.3, DC output voltage



(a) 15V buck converter

(b) 3.3V buck converter

Figure 24: Test results unit test 1.3, output voltage ripple

6.1.7 Unit test 1.4, AC supply test

To test the complete power supply, this test also tests the rectifier at the input stage.

6.1.8 Test results unit test 1.4

7.todo

Tested requirements	**REQ-1.1** The system shall operate on a voltage between 207V and 253V RMS. **REQ-1.2** The system shall be able to operate without the need of a neutral wire (2-wire). **REQ-5.1** The product will shut down when the temperature gets too high. **REQ-5.2** The product shall have overcurrent protection. **REQNF-1** The connectors shall be suitable for solid core 2.5mm^2 cables. **REQNF-2** The connectors shall be suitable for solid core 1.5mm^2 cables.
Required materials	Oscilloscope AC power supply or autotransformer Multimeter
Test criteria	The system will pass the test when: • The output voltage of the first buck converter is between 14.5V and 15.5V DC • The output voltage of the second buck converter is between 3V and 3.3V DC • The maximum output voltage ripple is 100mV$_{pp}$
Test procedure	Steps to test the unit: 1. Set the AC power supply to 0V AC 2. Connect a multimeter in AC mode to the power supply 3. Connect the AC power supply to the unit 4. Set the oscilloscope to DC coupling, 5V/div, 250µs/div 5. Connect a load resistor of 1kΩ to the output of the 15V buck converter 6. Connect a load resistor of 200Ω to the output of the 3.3V buck converter 7. Connect the oscilloscope to the output of the 15V buck converter 8. Switch on the AC power supply and bring up the voltage to 100V AC 9. Measure the DC output voltage of the 15V buck converter 10. Set the oscilloscope to DC coupling, 1V/div, 25µs/div 11. Connect the oscilloscope to the output of the 3.3V buck converter 12. Measure the DC output voltage of the 3.3V buck converter 13. Set the oscilloscope to AC coupling, 100mV/div, 250µs/div 14. Connect the oscilloscope to the output of the 15V buck converter 15. Measure the output voltage ripple of the 15V buck converter 16. Set the oscilloscope to AC coupling, 50mV/div, 25µs/div 17. Connect the oscilloscope to the output of the 3.3V buck converter 18. Measure the output voltage ripple of the 3.3V buck converter

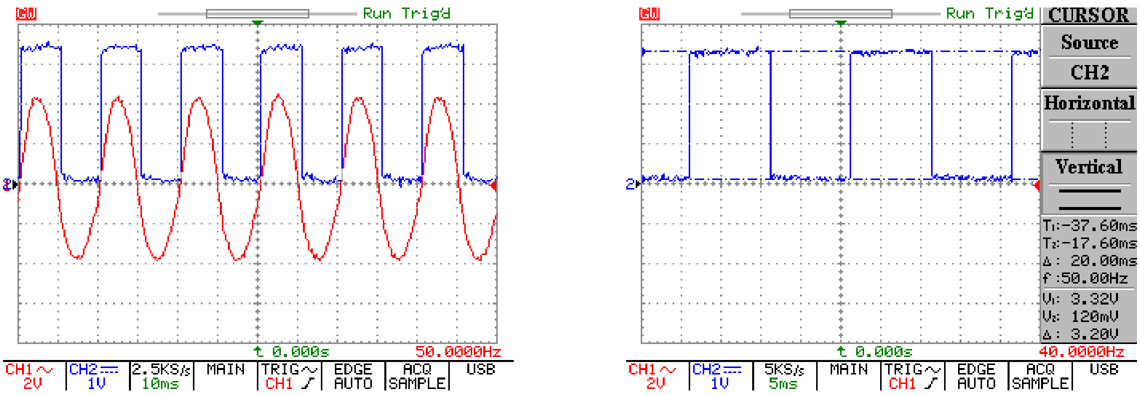
Table 11: Unit test 1.4, Power supply AC test

6.1.9 Unit test 1.5, zero-crossing detection

6.1.10 Test results unit test 1.5

Tested requirements	**REQ-1.4** Zero-crossings of the AC line shall be detected. **REQ-3.2** The relay shall be switched on a zero-crossing of the AC power.
Required materials	Oscilloscope Bench power supply Arbitrary waveform generator
Test criteria	The system will pass the test when: • The square wave toggles every time the input signal crosses 0V • The output voltage of the zero cross detector is between 0V and 3.3V
Test procedure	Steps to test the unit: 1. Set the DC power supply to 3.3V DC, set the current limit to 50mA 2. Connect the power supply to the unit 3. Set the arbitrary waveform generator to a sine wave of $8V_{pp}$ at a frequency of 50Hz 4. Set channel 1 of the oscilloscope to AC coupling, 2V/div, channel 2 to DC coupling, 1V/div, 10ms/div 5. Connect channel 1 of the oscilloscope to the output of the waveform generator and channel 2 to the output of the unit to measure the output voltage 6. Measure the voltage of the square wave

Table 12: Unit test 1.5, zero-crossing detection



(a) Input (red) and output (blue)

(b) Output measurement

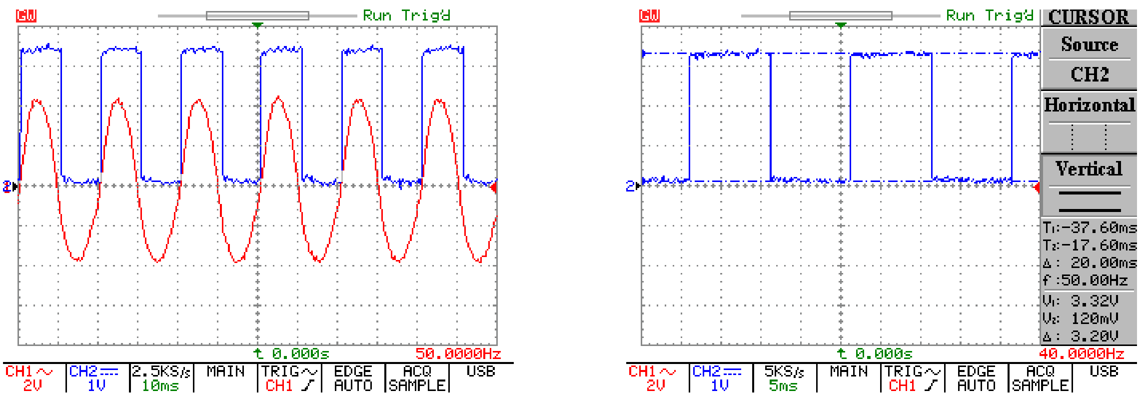
Figure 25: Test results unit test 1.5

6.1.11 Unit test 1.6, complete power supply test

6.1.12 Test results unit test 1.5

Tested requirements	**REQ-1.4** Zero-crossings of the AC line shall be detected. **REQ-3.2** The relay shall be switched on a zero-crossing of the AC power.
Required materials	Oscilloscope Bench power supply Arbitrary waveform generator
Test criteria	The system will pass the test when: • The square wave toggles every time the input signal crosses 0V • The output voltage of the zero-cross detector is between 0V and 3.3V
Test procedure	Steps to test the unit: 1. Set the DC power supply to 3.3V DC, set the current limit to 50mA 2. Connect the power supply to the unit 3. Set the arbitrary waveform generator to a sine wave of $8V_{pp}$ at a frequency of 50Hz 4. Set channel 1 of the oscilloscope to AC coupling, 2V/div, channel 2 to DC coupling, 1V/div, 10ms/div 5. Connect channel 1 of the oscilloscope to the output of the waveform generator and channel 2 to the output of the unit to measure the output voltage 6. Measure the voltage of the square wave

Table 13: Unit test 1.6, complete power supply test



(a) Input (red) and output (blue)

(b) Output measurement

Figure 26: Test results unit test 1.5

6.2 Microcontroller

6.2.1 Unit test 2.1, NAAM

6.2.2 Test results unit test 2.1

Tested requirements	**REQ-1.4** Zero-crossings of the AC line shall be detected. **REQ-3.2** The relay shall be switched on a zero-crossing of the AC power.
Required materials	Oscilloscope Bench power supply Arbitrary waveform generator Test code
Test criteria	The system will pass the test when: •
Test procedure	Steps to test the unit: 1.

Table 14: Unit test 2.1, NAAM

6.3 Dimmer

6.3.1 Unit test 3.1, NAAM

Tested requirements	**REQ-1.4** Zero-crossings of the AC line shall be detected. **REQ-3.2** The relay shall be switched on a zero-crossing of the AC power.
Required materials	Oscilloscope Bench power supply Arbitrary waveform generator
Test criteria	The system will pass the test when: •
Test procedure	Steps to test the unit: 1.

Table 15: Unit test 3.1, NAAM

6.3.2 Test results unit test 3.1

6.4 Integration Tests

6.4.1 Power supply and microcontroller

Tested requirements	
Required materials	Oscilloscope Bench power supply Test code
Test criteria	The system will pass the test when: •
Test procedure	Steps to test the unit: 1.

Table 16: Integration test 1, NAAM

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Glossary

LTE-M Long Term Evolution - Machine Type Communication, a low power wide-area network radio technology. 5

NB-IoT Narrowband Internet of Things, a low power wide-area network radio technology. 5

soft-fuse A passive electronic device used to protect against over-current in electronics. 5

standby-killer An electronic device that cuts electricity to devices that are in standby. 5

Thread A low power, IPv6 based, wireless mesh network protocol. 5

VDE German organization: Association for Electrical, Electronic & Information Technologies. An institute for testing and certification of electrical products.. 23

X-capacitor Safety rated capacitors, designed to be used in AC line filtering. 17

Zigbee A low power wireless mesh network protocol. 5

Acronyms

BLE Bluetooth Low Energy. 5, 8, 22, 23

GPIO General Purpose Input/Output. 15

IGBT Insulated-gate bipolar transistor. 17

LDO Low Dropout Regulator. 18

LiPo Lithium-polymer. 3, 8, 9, 11

NiMH Nickel-Metal hydride. 3, 8, 9, 11

PWM Pulse Width Modulation. 15

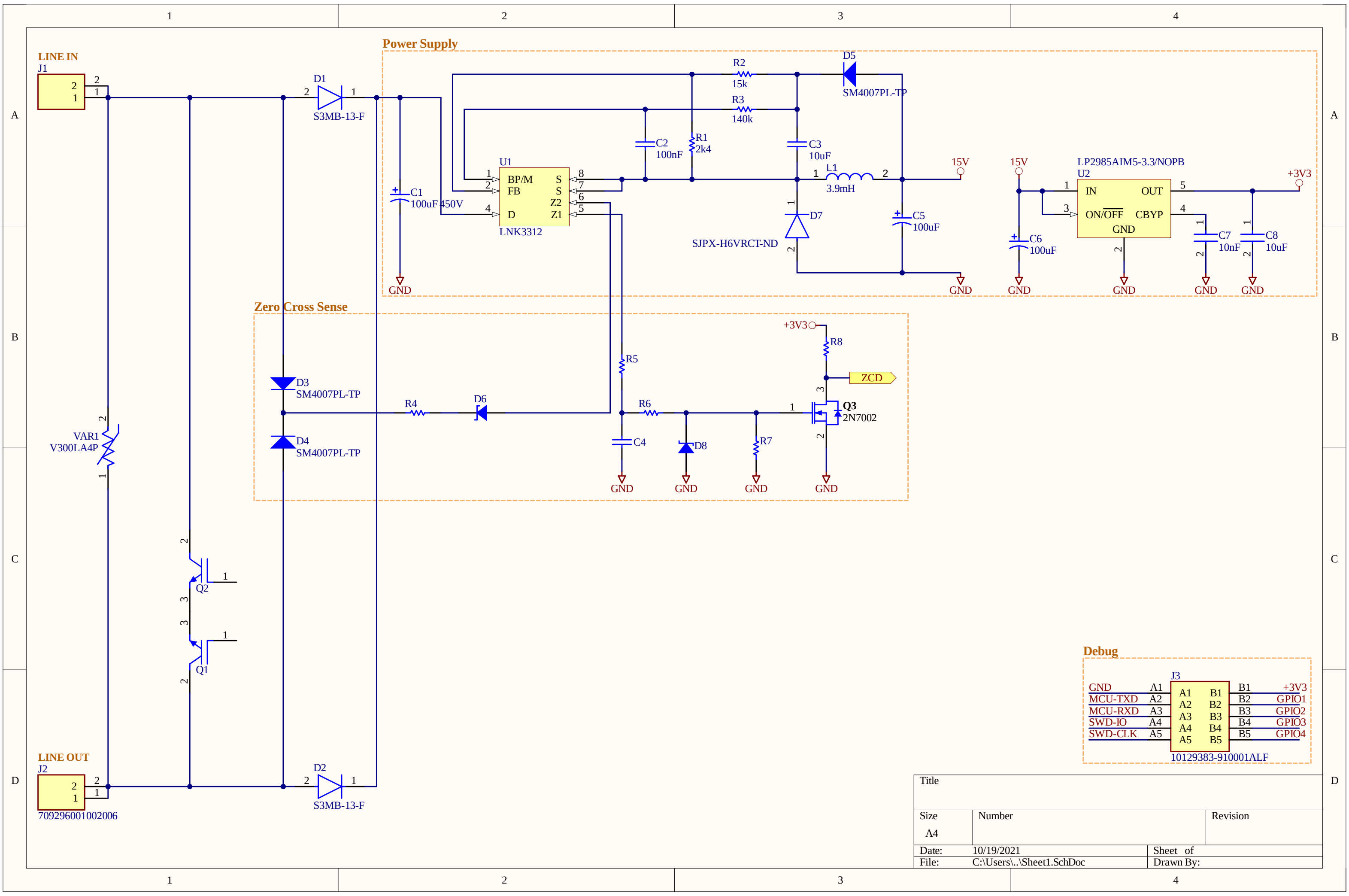
SiP System-in-Package. 5

SoC System-on-Chip. 5, 7, 8, 11, 12, 15, 17, 18, 21, 22, 23

SWD Serial Wire Debug. 12, 15

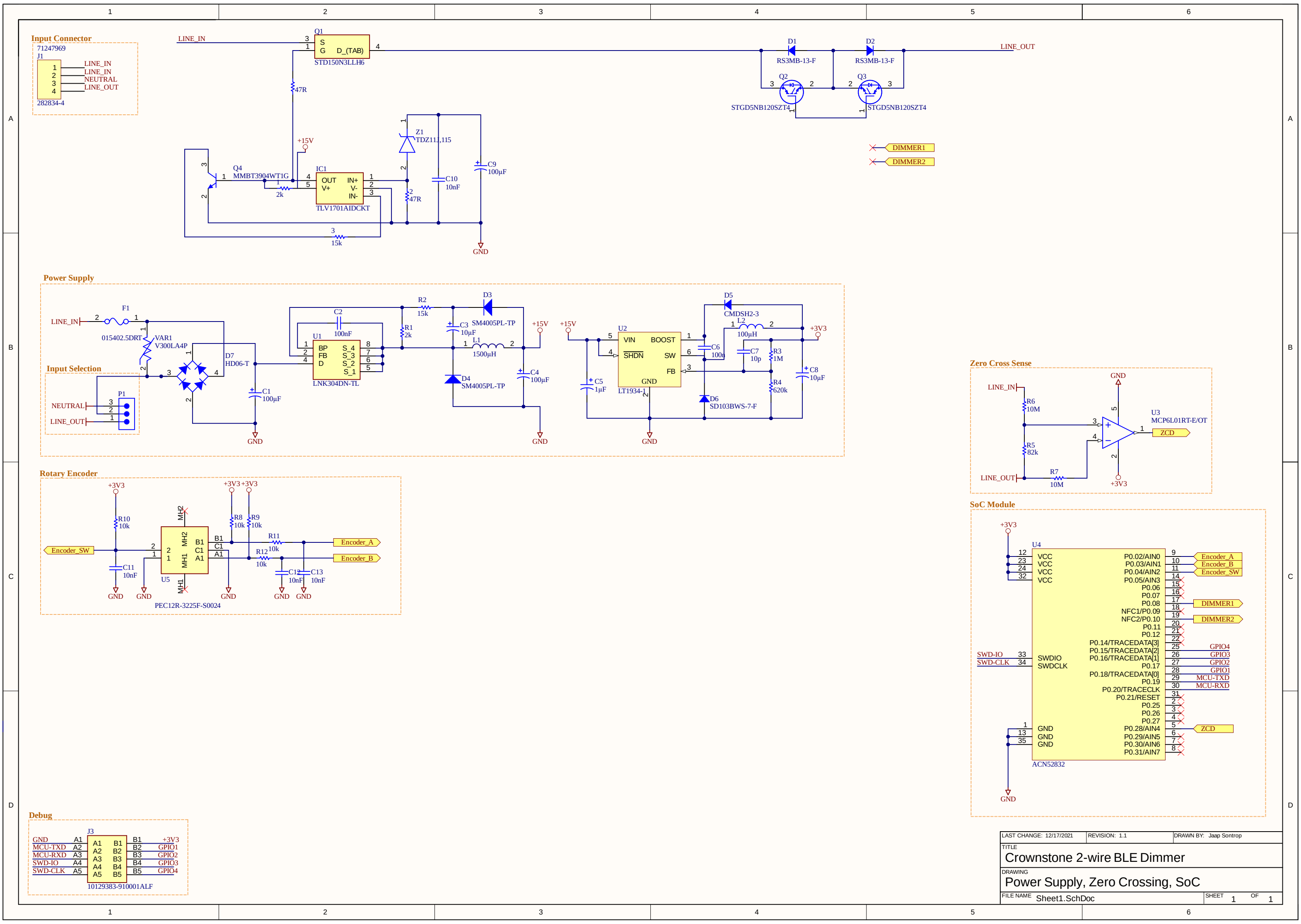
UART Universal Asynchronous Receiver-Transmitter. 15, 23

A Schematic V1



Power Supply
Zero Cross Sense
Debug
LINE IN
J1
LINE OUT
J2
709296001002006
D1
S3MB-13-F
D2
S3MB-13-F
C1
100uF 450V
U1
LNK3312
BP/M
FB
D
S
S
Z2
Z1
C2
100nF
R1
2k4
R2
15k
R3
140k
C3
10uF
D5
SM4007PL-TP
L1
3.9mH
D7
SJPX-H6VRCT-ND
C5
100uF
15V
GND
U2
LP2985AIM5-3.3/NOPB
IN
OUT
ON/OFF
CBYP
C6
100uF
C7
10nF
C8
10uF
+3V3
D3
SM4007PL-TP
D4
SM4007PL-TP
R4
D6
R5
R6
C4
D8
R7
R8
ZCD
Q3
2N7002
VAR1
V300LA4P
Q1
Q2
J3
10129383-910001ALF
GND
MCU-TXD
MCU-RXD
SWD-IO
SWD-CLK
GPIO1
GPIO2
GPIO3
GPIO4
Title
Size
A4
Number
Revision
Date:
10/19/2021
Sheet of
File:
C:\Users\..\Sheet1.SchDoc
Drawn By:

B Schematic V1.3



Input Connector
71247969
J1
LINE_IN
LINE_IN
NEUTRAL
LINE_OUT
282834-4
Q1
STD150N3LLH6
D1
RS3MB-13-F
D2
RS3MB-13-F
LINE_OUT
Q2
STGD5NB120SZT4
Q3
STGD5NB120SZT4
DIMMER1
DIMMER2
Q4
MMBT3904WT1G
IC1
TLV1701AIDCKT
Z1
TDZ11,115
C9
100µF
C10
10nF
GND
Power Supply
F1
015402.5DRT
VAR1
V300LA4P
D7
HD06-T
C1
100µF
U1
LNK304DN-TL
C2
100nF
R2
15k
D3
SM4005PL-TP
C3
10µF
L1
1500µH
D4
SM4005PL-TP
C4
100µF
U2
LT1934-1
C5
1µF
D5
CMDSH2-3
L2
100µH
C6
100n
C7
10p
R3
1M
R4
620k
C8
10µF
D6
SD103BWS-7-F
+15V
+3V3
Input Selection
P1
NEUTRAL
LINE_OUT
Zero Cross Sense
LINE_IN
R6
10M
R5
82k
R7
10M
U3
MCP6L01RT-E/OT
ZCD
Rotary Encoder
R10
10k
Encoder_SW
C11
10nF
U5
PEC12R-3225F-S0024
R8
10k
R9
10k
R11
10k
R12
10k
C12
10nF
C13
10nF
Encoder_A
Encoder_B
SoC Module
U4
ACN52832
SWD-IO
SWD-CLK
Encoder_A
Encoder_B
Encoder_SW
DIMMER1
DIMMER2
GPIO4
GPIO3
GPIO2
GPIO1
MCU-TXD
MCU-RXD
ZCD
Debug
J3
10129383-910001ALF
GND
MCU-TXD
MCU-RXD
SWD-IO
SWD-CLK
+3V3
GPIO1
GPIO2
GPIO3
GPIO4
LAST CHANGE: 12/17/2021
REVISION: 1.1
DRAWN BY: Jaap Sontrop
TITLE
Crownstone 2-wire BLE Dimmer
DRAWING
Power Supply, Zero Crossing, SoC
FILE NAME Sheet1.SchDoc
SHEET 1 OF 1

C PI Expert LinkSwitch-TNZ Buck converter design

ACDC_LinkSwitchTNZ_Buck_052621; Rev.1.0; Copyright Power Integrations 2021	***INPUT***	***INFO***	***OUTPUT***	***UNIT***	***ACDC LinkSwitch-TNZ Buck***
ENTER APPLICATION VARIABLES					*Design Title*
LINE VOLTAGE RANGE			*High Line*		*AC line voltage range*
VACMIN	*207.00*		*207.00*	*V*	*Minimum AC line voltage*
VACMAX	*253.00*		*253.00*	*V*	*Maximum AC line voltage*
fL	*50.00*		*50.00*	*Hz*	*AC mains frequency*
LINE RECTIFICATION TYPE	*H*		*H*		*Line rectification type: select "F" if full wave rectification or "H" if half wave rectification*
VOUT	*15.00*		*15.00*	*V*	*Output voltage*
IOUT	*0.080*		*0.080*	*A*	*Average output current*
EFFICIENCY_ESTIMATED			*0.80*		*Efficiency estimate at output terminals*
EFFICIENCY_CALCULATED			*0.84*		*Calculated efficiency based on real components and operating point*
POUT			*1.20*	*W*	*Continuous output power*
CIN	*3.30*		*3.30*	*uF*	*Input capacitor*
VMIN			*263.5*	*V*	*Valley voltage of the rectified minimum AC line voltage*
VMAX			*357.8*	*V*	*Peak voltage of the maximum AC line voltage*
INPUT STAGE RESISTANCE	*5*		*5*	*Ohms*	*Input stage resistance in ohms (includes thermistor, filtering components, etc)*
PLOSS_INPUTSTAGE			*0.000*	*W*	*Maximum input stage loss*
ENTER LINKSWITCH-TNZ VARIABLES					
OPERATION MODE			*MCM*		*Mostly continuous mode of operation*
CURRENT LIMIT MODE	*STD*		*STD*		*Choose 'RED' for reduced current limit or 'STD' for standard current limit*
XCAP REQUIRED	*YES*		*YES*		*Select whether an X-capacitor is required or not*
PACKAGE			*SO-8C*		*Device package*
DEVICE SERIES	*LNK3312*		*LNK3312*		*Generic LinkSwitch-TNZ device*
DEVICE CODE			*LNK3312D*		*Required LinkSwitch-TNZ device*
ILIMITMIN			*0.126*	*A*	*Minimum current limit of the device*
ILIMITTYP			*0.136*	*A*	*Typical current limit of the device*
ILIMITMAX			*0.146*	*A*	*Maximum current limit of the device*
RDSON			*88.40*	*ohms*	*Primary switch on-time drain to source resistance at 100degC*
FSMIN			*62000*	*Hz*	*Minimum switching frequency*
FSTYP			*66000*	*Hz*	*Typical switching frequency*
FSMAX			*70000*	*Hz*	*Maximum switching frequency*
BVDSS			*725*	*V*	*Device breakdown voltage*
SWITCH PARAMETERS					
VDSON			*2.00*	*V*	*Switch on-time drain to source voltage estimate*
VDSOFF			*375.7*	*V*	*Switch off-time drain-to-source voltage stress*
DUTY			*0.063*		*Maximum duty cycle*
TIME_ON_MIN			*1.947*	*us*	*Switch minimum on-time*
IPED_SWITCH			*0.037*	*A*	*Maximum switch pedestal current*
IRMS_SWITCH			*0.022*	*A*	*Maximum switch RMS current*

PLOSS_SWITCH			*0.078*	*W*	*Maximum switch loss*
THERMAL RESISTANCE OF SWITCH			*100*	*degC/W*	*Net thermal resistance of the switch*
T_RISE_SWITCH			*7.8*	*degC*	*Maximum temperature rise of the switch in degrees Celsius*
BUCK INDUCTOR PARAMETERS					
INDUCTANCE_MIN			*7380*	*uH*	*Minimum design inductance required for current delivery*
INDUCTANCE_TYP	*8200*		*8200*	*uH*	*Typical design inductance required for current delivery*
INDUCTANCE_MAX			*9020*	*uH*	*Maximum design inductance required for current delivery*
TOLERANCE_INDUCTANCE	*10*		*10*	*%*	*Tolerance of the design inductance*
DC RESISTANCE OF INDUCTOR	*1.1*		*1.1*	*ohms*	*DC resistance of the buck inductor*
FACTOR_KLOSS			*0.50*		*Factor that accounts for "off-state" power loss to be supplied by inductor (usually between 50% to 66%)*
IRMS_INDUCTOR			*0.088*	*A*	*Maximum inductor RMS current*
PLOSS_INDUCTOR			*0.009*	*W*	*Maximum inductor losses*
FREEWHEELING DIODE PARAMETERS					
VF_FREEWHEELING	*1.50*		*1.50*	*V*	*Forward voltage drop across the freewheeling diode*
PIV_RATING			*600.0*	*V*	*Peak inverse voltage rating of the freewheeling diode*
TRR			*30*	*ns*	*Reverse recovery time of the freewheeling diode*
PIV_CALCULATED			*447.2*	*V*	*Computed peak inverse voltage across the freewheeling diode*
IRMS_DIODE			*0.086*	*A*	*Maximum diode RMS current*
PLOSS_DIODE			*0.132*	*W*	*Maximum freewheeling diode loss*
RECOMMENDED DIODE			*BYV26C*		*Recommended freewheeling diode*
BIAS/FEEDBACK PARAMETERS					
VF_BIAS	*1.10*		*1.10*	*V*	*Forward voltage drop of the bias diode*
RBIAS	*2400*		*2400*	*Ohms*	*Bias resistor (connected across FB and S pin). Results into IFB_BIAS value of 833.333 uA*
RBP			*140000*	*Ohms*	*BP pin resistor*
CBP			*0.1*	*uF*	*BP pin capacitor*
RFB			*15000*	*Ohms*	*Feedback resistor*
CFB			*10*	*uF*	*Feedback capacitor*
C_SOFTSTART			*1-10*	*uF*	*If the output voltage is greater than 12 V or total output and system capacitance is greater than 100 uF, a soft start capacitor between 1uF and 10 uF is recommended*
PLOSS_FEEDBACK			*0.013*	*W*	*Maximum feedback component losses*
X-CAPACITOR DISCHARGE COMPONENTS					
XCAP			*100.0*	*nF*	*X-capacitor in the input*
TOLERANCE_RZ	*0.05*		*5%*		*Tolerance of the X-capacitor discharge resistors*
RZ1			*2.37*	*MOhms*	*X-capacitor discharge resistor connected from the input line to Z1 pin of LinkSwitch-TNZ device*

RZ2			2.37	MOhms	X-capacitor discharge resistor connected from the input neutral to Z2 pin of LinkSwitch-TNZ device
t_XCAP_DISCHARGE			0.889	sec	Actual time (worst-case) to discharge the X-capacitor to 60 V after AC input disconnection
OUTPUT CAPACITOR					
OUTPUT VOLTAGE RIPPLE			300	mV	Desired output voltage ripple
IRMS_COUT			0.037	A	Maximum output capacitor RMS current
PLOSS_COUT			0.005	W	Maximum output capacitor power loss
ESR_COUT			3510	mOhms	ESR of the output capacitor

D PI Expert LinkSwitch-TN Buck converter design

E Competentieverantwoording

8.todo, competentieverantwoording

F Reflectie

9.todo, reflectie

G Tussentijdse beoordeling

Tussenbeoordeling bedrijfsbegeleider stage

Geachte bedrijfsbegeleider,
Uw tussentijdse beoordeling van de stagiair is voor belangrijke input voor zijn/haar ontwikkeling. Daarom vragen wij u dit formulier halverwege de stage in te vullen en met de stagiair te bespreken. Kruist u de punten aan die van toepassing zijn. Voor extra op- en aanmerkingen hebben we ook ruimte gelaten. Hartelijk dank voor uw medewerking.

Bedrijfsbegeleider: Dr. Ir. A. C. van Rossum

Bedrijf: Crownstone

Naam student: Jaap Sontrop

Studentnr: 0989157

A. ANALYSEREN, ONTWERPEN, REALISEREN en BEHEREN

1: ontbrekend of onvoldoende
2: vraagt nog wat aanpassing of toevoeging
3: redelijk
4: goed

ANALYSEREN

1 / 2 / 3 / **4** - het programma van eisen is een onderbouwde technische vertaling van de wensen van de opdrachtgever;
1 / 2 / 3 / **4** - de probleemstelling komt overeen met de opdracht/de doelstelling is conform de eisen van de opdrachtgever;
1 / 2 / 3 / **4** - er is afweging gemaakt voor mogelijke oplossingsrichtingen op essentiële momenten;

Opmerkingen: Voorbeelden van afwegingen zijn bijv. de keuze voor de voeding of voor de nuldoorgangsmeting.

ONTWERPEN

1 / 2 / 3 / 4 - het ontwerp voldoet aan de kwaliteitseisen van het bedrijf;

Opmerkingen: Ziet er tot nog toe goed uit, maar het gehele ontwerp is nog niet af. Dus te vroeg.

REALISEREN

1 / 2 / 3 / 4 - het product/de simulatie is als geheel testbaar;
1 / 2 / 3 / 4 - er is vastgesteld of het product al dan niet aan de eisen voldoet die zijn meegenomen in het ontwerp;
1 / 2 / 3 / 4 - de testen zijn conform de gekozen ontwerpmethodiek uitgevoerd;

Opmerkingen: Dit is 50% beoordeling. Dit is nog te vroeg.

BEHEREN

1 / 2 / 3 / 4 - er is een gebruiks-, onderhouds- en/of inbedrijfstellingshandleiding opgesteld;
1 / **2** / 3 / 4 - de projectdocumentatie is volledig en volgens de bedrijfsconventies opgesteld.

Opmerkingen: Dit is 50% beoordeling. Te vroeg voor handleidingen. Documentatie kan wel beter (ook in dit stadium).

B. MANAGEN, ONDERZOEKEN, PROFESSIONALISEREN en ADVISEREN

MANAGEN

1 / 2 / 3 / **4** - het plan van aanpak bevat alle noodzakelijke onderdelen en is systematisch uitgewerkt;

1 / 2 / 3 / **4** - er is een uitgewerkte planning vastgelegd;

1 / 2 / **3** / 4 - alle mogelijke risico's zijn in kaart gebracht;

1 / 2 / **3** / 4 - de planning en risico's zijn tussentijds geëvalueerd;

1 / 2 / **3** / 4 - de stakeholders van het project zijn op de hoogte gehouden van de planning en voortgang;

1 / 2 / **3** / 4 - de student heeft de projectdocumentatie verzorgd volgens de binnen het bedrijf geldende normen;

Opmerkingen: Planning is goed vastgelegd, maar kan (incl. risico's) meer proactief met de begeleider worden doorgenomen.

ONDERZOEKEN

1 / 2 / **3** / 4 - op relevante momenten werd benodigde data verkregen door onderzoek dan wel uit betrouwbare bronnen;

Opmerkingen: Er wordt beide theoretisch gezocht en empirisch gecontroleerd. Communiceren over de betrouwbaarheid van desbetreffende data kan nog wel beter.

PROFESSIONALISEREN

1 / 2 / **3** / 4 - er is effectief met de opdrachtgever en bedrijfsbegeleider gecommuniceerd;

1 / 2 / 3 / **4** - de student heeft cruciale feedback van bedrijfsbegeleider aangenomen of met onderbouwing verworpen;

1 / 2 / **3** / 4 - de zelfstandigheid van de student en vragen aan de bedrijfsbegeleider waren in de juiste balans;

1 / 2 / **3** / 4 - potentiële problemen en fouten zijn voorkomen door tijdige reflectie op handelen en omstandigheden;

1 / 2 / 3 / **4** - de student heeft besluiten genomen conform de maatschappelijke normen;

1 / 2 / **3** / 4 - de student heeft effectief gehandeld en gecommuniceerd in een internationale, multidisciplinaire en/of interdisciplinaire werkomgeving.

Opmerkingen: Communicatie is goed, maar ik kan nog beter inzicht krijgen in potentiele problemen en zou meer vragen verwachten.

ADVISEREN

1 / 2 / 3 / 4 - tijdens het proces heeft de student aan de opdrachtgever waardevolle adviezen gegeven;

1 / 2 / 3 / 4 - de adviezen over vervolgstappen om het gerealiseerde ontwerp te verbeteren zijn volledig en eenduidig.

Opmerkingen: Te vroeg

C. TOT SLOT

Welke advies wilt u de student meegeven voor het verder verloop van de stage?

Communiceer proactief. Email meer met Peet met mij in CC. Neem mensen mee in je denkproces.

Beoordelaar:
Datum: Handtekening:

PS: de student voegt dit ondertekende formulier als bijlage toe aan zijn/haar definitieve stageverslag.