Low Power Wakeup-Receiver

Project Electrical Engineering AS2019

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Subject
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Abstract

Introduction

In company buildings, universities and other similar facilities, it is usual to attach occupancy schedules next to room entrances. These schedules are mostly printed on paper, or in more modern buildings, displayed on a screen. Using paper, it is impracticable to take short-term changes into account, since every adjustment needs to be made by printing a new schedule. Screens on the other hand need either to be connected to a power supply, which entails extensive installation work, or are powered by a battery, which needs to be replaced from time to time. All these disadvantages could be avoided by using a screen which harvests its energy from the indoor light, and is updated via a wireless interface. The screen should therefore be completely wireless, which simplifies the installation.

Approach

Solar cells should harvest the required energy which can be store in a super-capacitor. Because this harvesting unit cannot provide unlimited energy, the whole system with display, microcontroller and wireless interface should consume as little energy as possible. To achieve this, a e-paper display is used, which only needs energy to update the screen, but not to maintain the displayed data. By using a wake up receiver, it is now possible to disconnect the energy storage from the system, since it can be reconnected again when needed if a wake up interrupt is detected. In a nutshell, the display, microcontroller and interface can be completely disconnected from the power supply when not used. In this state, only the leakage of the super-capacitor and the wakeup receiver in listening mode consume power. This consumption is in the micro watt range.

Conclusion

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Abbreviations

IIS Fraunhofer-Institut für Integrierte Schaltungen

ASK Amplitude Shift Keying

OOK On-Off Keying

GUI Graphical User Interface

SPI Serial Peripheral Interface

Chapter 1

Introduction

In company buildings, universities and other similar facilities, it is usual to attach occupancy schedules next to room entrances. These schedules are mostly printed on paper, or in more modern buildings, displayed on a screen. Using paper, it is impracticable to take short-term changes into account, since every adjustment needs to be made by printing a new schedule. Screens on the other hand need either to be connected to a power supply, which entails extensive installation work, or are powered by a battery, which needs to be replaced from time to time. All these disadvantages could be avoided by using a screen which can be updated wireless and is in itself autarkic. The goal of this semester thesis is to develop a functional prototype of such a schedule.

1.1 Task analysis

The prototype should combine both the advantages of the paper method and the screen. Updating should happen via a wireless interface while a expensive installation should be avoided. The screen should therefore be placed on the desired location just like a paper schedule. To consume as low power as possible, the microcontroller, display and interface should be switched off when not needed.

1.2 Approach

Chapter 2

Theory

2.1 E-Paper Display

There are several different technologies which are applied in e-paper displays. But since the developed prototype uses a microencapsulated electrophoretic display, this section only describes this specific implementation.

A film, consisting of microscopic capsules, is coated onto a backplane, which basically is a matrix of electrodes. On top of that comes a common electrode, called the frontplane. This setup is shown in figure 2.1.

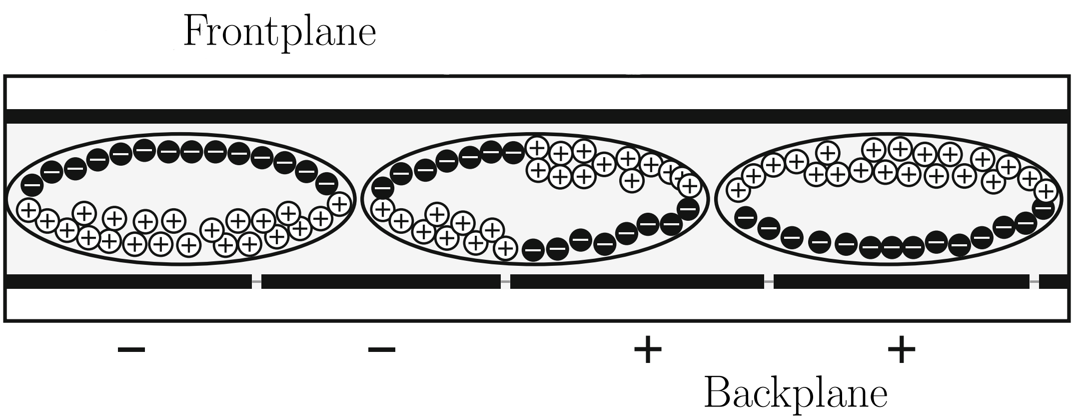


Figure 2.1: filler pic

Each capsule in the film itself contains a transparent fluid and particles of two opposite charges. One type of particle scatters the light while the other one absorbs it. The particles now begin to move in opposite directions thought the fluid when exposed two a electrical field. The pixel (defined by the electrode size) appears white if the scattering particles ar near the frontplane and black if otherwise. If no voltage is applied to the electrodes, the particles maintain their last position. This makes it possible to switch of the power supply when no image update is needed which is the reason why the power consumption is strongly reduced compared to other types of display [1].

Figure 2.2 shows a e-paper display with 250x magnification. One electrode is coated by many capsules, which are between 0.02 mm and 0.04 mm in diameter.

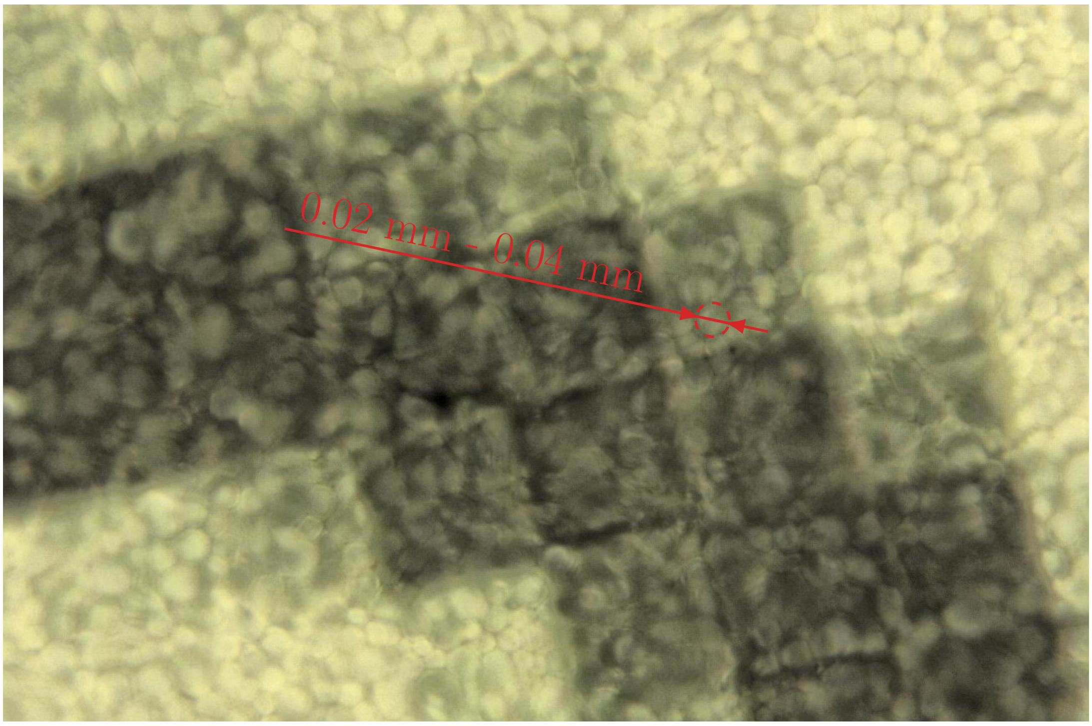


Figure 2.2: E-paper display under microscope with 250x magnification

2.2 Wakeup Receiver

To safe power with an conventional receiver, it needs to be programmed in such a way, that it is kept in a sleep mode. To check if any data was sent, it needs to wake up periodically to check for notifications. To set this duty cycle is a trade off between response time and power consumption. Is the period longer, the receiver is a also longer time in its sleep mode. On the other side defines this period directly the response time, since data can only be received in the running mode. A wakeup receiver now allows a device to be constantly in listening mode, while consuming low energy. Added to the system, the actual microcontroller, which coordinates the data transmission and other tasks stays shut down with only the wakeup receiver in listening mode. After receiving a defined pattern over this channel, the wakeup receiver generates an interrupt to wake up the microcontroller. It can now establish a channel over a different wireless module, or execute another task. When done, the microcontroller puts itself and all other modules except the wakeup receiver in sleep mode again. Figure 2.3 shows a comparison of both the conventional approach and the solution with the wakeup receiver.

One can argue, that the wakeup receiver module consumes in general more power, than the microcontroller in sleep mode. But since the microcontroller only wakes up, when a task needs to be done, the overall energy consumption (area underneath the curves summarized) is going to be smaller if the occurring wakeup event comes infrequently or over longer periods of time. The response time on the other hand can be kept in the microsecond range.

2.3 software grafik zeichen

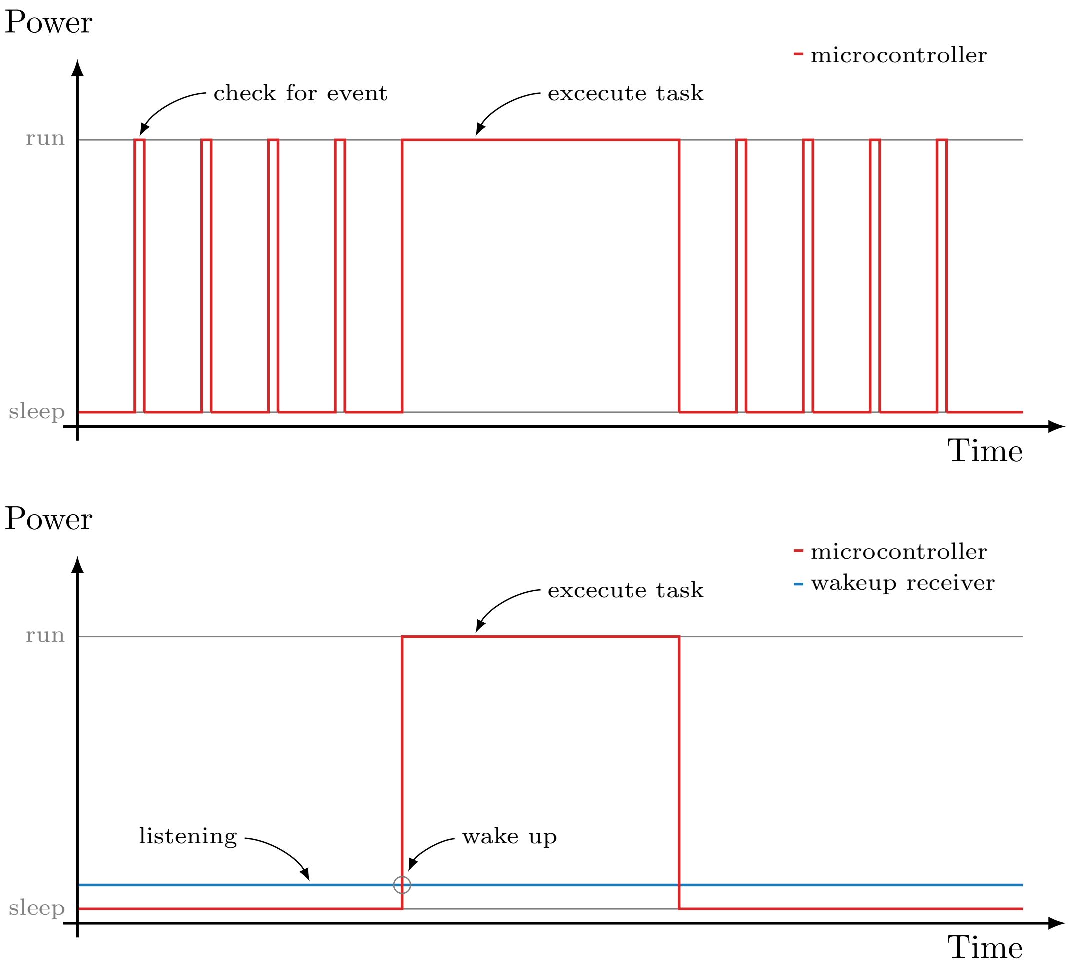


Figure 2.3: Microcontroller checks periodically for incoming data (top), additional, constantly listening wakeup receiver (bottom)

Chapter 3

Evaluation

This chapter lists the pros and cons of available Technologies. On this basis was evaluated, which hardware is suitable.

3.1 Wakeup Receiver

In this semester thesis, two different implementations of the wakeup receiver technology were compared. The AS3933 from AMS and the RFicient from the Fraunhofer-Institut für Integrierte Schaltungen (IIS) which kindly provided an evaluation kit before the actual release of the product.

3.1.1 AS3933

The AS3933 is a low frequency wakeup receiver, which uses ASK to modulate a carrier frequency between 15-150 kHz. The transmitter sends a manchester encoded, programmable wakeup pattern of length 16 or 32 bit. If this pattern is detected on the receiver end, a wakeup interrupt is generated. It is also possible to disable the the pattern decoder to run the chip in a frequency detection mode, where a wakeup interrupt is generated as soon as any pattern on the specified frequency is received. More important features on the receiver end are:

- Receiver sensitivity $80\,\mu V_{RMS}$
- Current consumption in 3-channel listening mode $2.3\,\mu A$
- Operating supply range 2.4 V – 3.6 V
- Three antennas (enables 3D detection)
- Channels individually selective to reduce power consumption

The low power consumption makes it possible run the receiver in listening mode below $8.3\,\mu W$[2].

The demo kit comes with a GUI, which enables the user to set the parameters as desired and adress the registers directly. The range of the receiver of about 6 m as first measurement turns out to be very limited. Even with a 3db sensitivity boost on the receiver side, it is only possible to detect wakeup events from a distance of 9 m. The environment (indoor, outdoor) seems to make no huge difference.

As a result, the limited range makes the AS3933 unusable for the prototype.

3.1.2 RFicient

The Rficient from the IIS uses OOK to modulate a 868 MHz signal. It can either run in pure wakeup mode, where the receiver generates an interrupt as soon as a code is received or a selective mode, where a 16 bit wakeup preamble needs to match the receiver. After the preamble is detected, the data rate can be changed to transfer more bits which can be sent over an SPI-bus to a connected device. This way, it is possible to transmit data bits after the actual wakeup. Data rates can be set in a range between 256 bp/s – 32 kbp/s. The most important features are:

- Receiver sensitivity -80 dBm
- Energy consumption 3 μA at 1.5 V (data rate 1 kbit/s)
- Unidirectional data transfer possible

The power consumption therefore is in listening mode (data rate = 1 kb/s) 4.5 μW.

Just as the AS3933, the RFicient demo kit comes with a GUI, which enables the user to set the important parameters and access the register [3]. First measurements showed that the range of the RFicient is far higher than the range of the AS3933. It is therefore used in the prototype.

Chapter 4

Development

4.1 Hardware

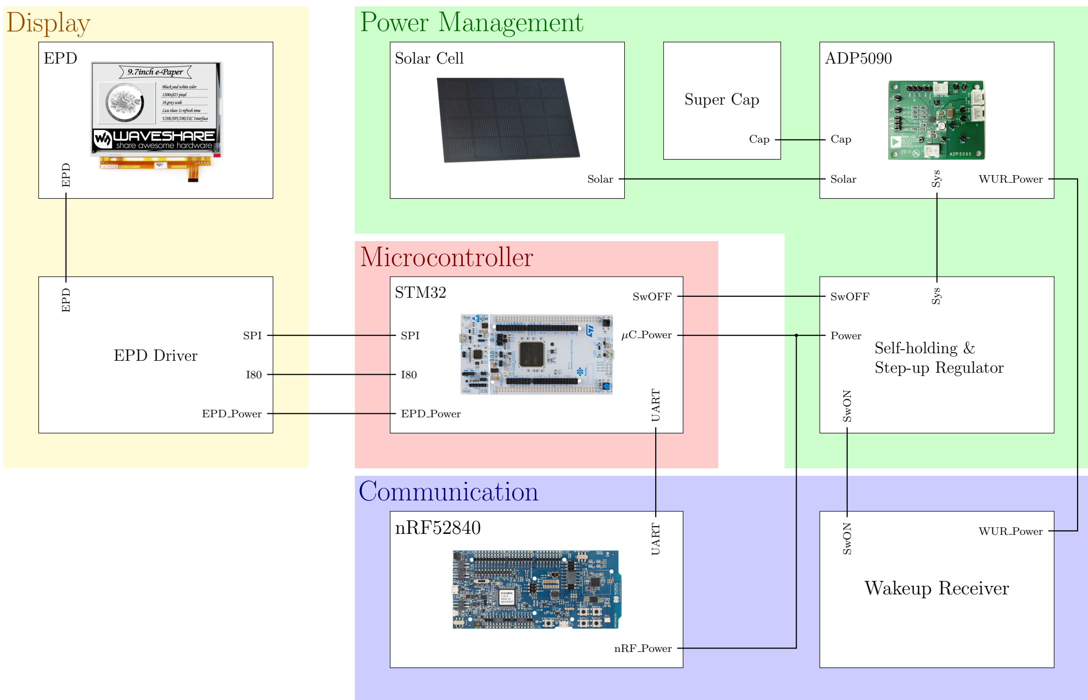


Figure 4.1: Receiver schematics

4.1.1 RFicient

The Rficient demo kit comes, as previously statet with a GUI.

Is the transceiver module connected, simple steps make it possible, to set the preamble and payload data rate and the payload itself which can partly serve as an ID and transmitted data. The power of the transmission can also be set between -30 dBm an 10 dBm. the transceiver-GUI is shown in figure 4.2.

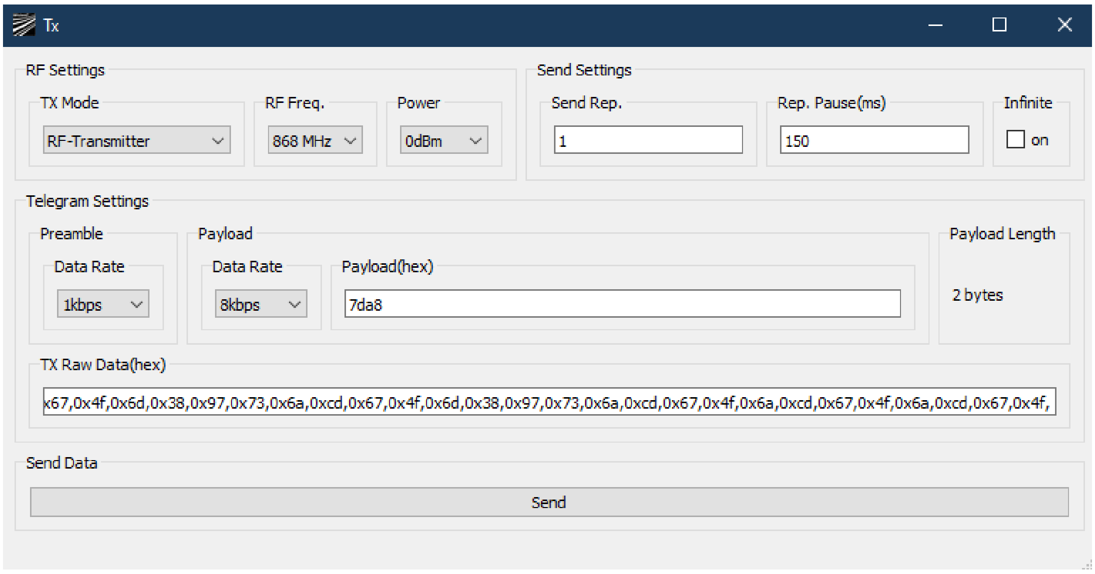


Figure 4.2: TX GUI

4.1.2 Energy Harvesting

The screen should be self-sustaining, thus some sort of energy-harvesting unit is needed. It was apparent to choose light as the energy source, since the screen will be used in rooms, that are artificially illuminated most of the time. The energy obtained by solar cells is converted to a suitable voltage, using a ADP5090 chip. This way, a super-capacitor, which is used as an energy storage device, is charged.

Solar cell

As solar cell, the AM-1522 by Panasonic is used. One panel has an area of 55.0 mm $\times$ 40.5 mm and delivers up to 58.7 μA when operating at an optimal voltage of 2.1 V, provided an illuminance of 200 lux. To keep a reasonable display to panel ratio, four cells where connected in parallel, which corresponds to an area of ca. 89.1 cm^2 (Display area = 283 cm^2). Therefore, the solar cells should provide a power of

$$P = U \cdot I = 4 \cdot 57.8\,\mu\text{A} \cdot 2.1\ \text{V} = 485.52\,\mu\text{W}, \tag{4.1}$$

given a 200 lux illuminance [4].

Power management

The ADP5090 from Analog Devices is used on the power management. This boost regulator makes it possible to charge storage elements, such as rechargeable batteries and super capacitors with the input dc-power provided by the PV-cell. Utilized features are:

- Maximum power point tracking
- Efficiency up to 90%
- Input voltage V_{IN} from 80 mV to 3.3 V

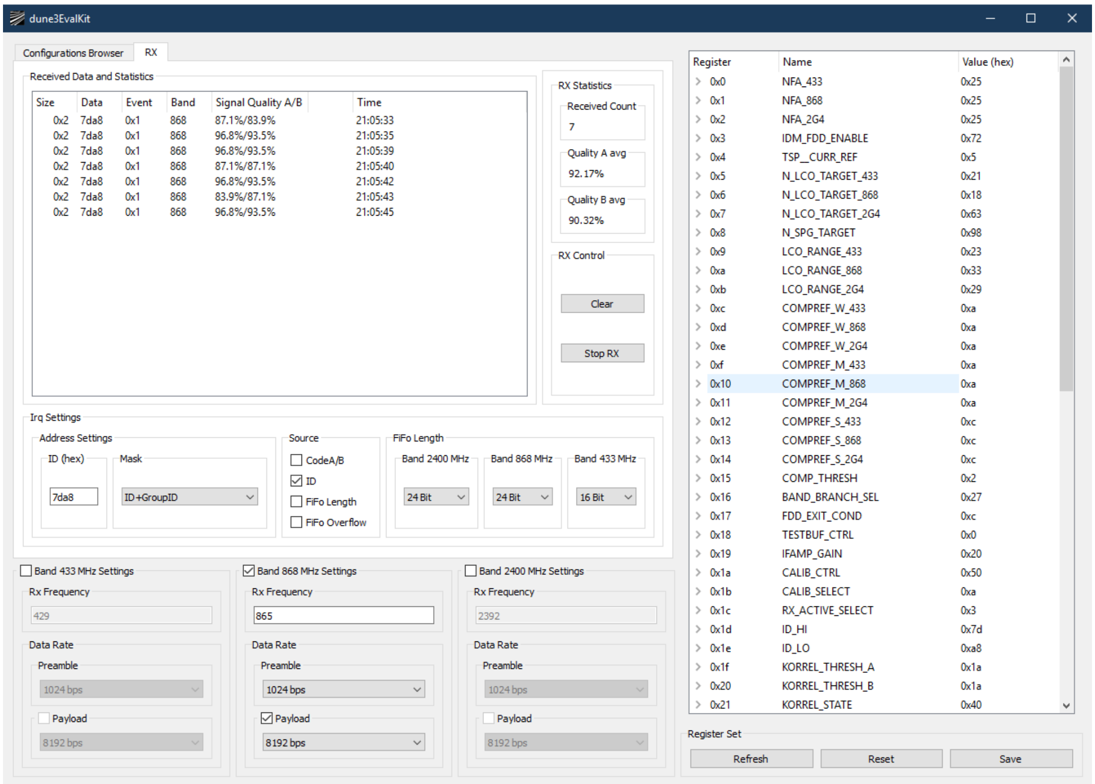


Figure 4.3: RX GUI

- Programmable voltage range (2.2 V to 5.2 V) for the storage element

To prevent the storage element from overdischarging, the ADP5090 enables the user to set a maximal Voltage with resistors:

$$V_{\mathrm{BAT\_TERM}} = \frac{3}{2} V_{\mathrm{REF}} \left(1 + \frac{R_{\mathrm{TERM1}}}{R_{\mathrm{TERM2}}} \right). \tag{4.2}$$

The same procedure is applied to set a minimal voltage:

$$V_{\mathrm{BAT\_SD}} = V_{\mathrm{REF}} \left(1 + \frac{R_{\mathrm{SD1}}}{R_{\mathrm{SD2}}} \right). \tag{4.3}$$

While discharging, the ADP5090 will switch off the output V_{SYS} if $V_{\mathrm{BAT\_SD}}$ is reached. This prevents the storage element from overdischarging. The output voltage V_{SYS}, where the load is attached, will therefore always stay in this programmed range ($V_{\mathrm{BAT\_SD}} \leq V_{\mathrm{SYS}} \leq V_{\mathrm{BAT\_TERM}}$) [5].

For this prototype, the evaluation board for the ADP5090 was used, where the internal reference voltage (V_{REF} in (4.2) and (4.3)) is 1.21 V [6].

Super capacitor

As energy storage, a super capacitor from Taiyo Yuden (LIC1235RS3R8406) has proven to be suitable, which is a 40 F cylinder type lithium ion capacitor. The operating voltage range is

Figure 4.4: Test environment 1 (filler)

between 2.2 V and 3.8 V. Discharging the capacitor lower than 2.2 V causes shorter lifetime and higher leakage current. The same unwanted behaviour occurs when charging the capacitor over 3.8 V [7].

Combined test

To test the behaviour of the power management, supercapacitor and solar cells, a couple of measurements are executed. Figure 4.6 shows the layout of the test setup.

To carry out these measurements, it is first necessary to adjust the minimal and maximal voltage of the ADP5090. The nrf58240 accepts supply voltages between 1.6 V up to 5.5 V [8]. The STM32 on the other side is less flexible with an input voltage range of 1.71 V to 3.6 V [9]. As stated in the section above, the super capacitors operating voltage is between 2.2 V and 3.8 V. Hence it seems reasonable, to set $V_{\text{BAT\_TERM}} \leq 3.6\,\text{V}$ and $V_{\text{BAT\_SD}} \geq 2.2\,\text{V}$, to satisfy all of these three elements. In order to do this, the four resistors have to be chosen as $R_3 = 4.3\,\text{M}\Omega$, $R_6 = 4.7\,\text{M}\Omega$, $R_2 = 4.3\,\text{M}\Omega$ and $R_3 = 5.1\,\text{M}\Omega$. Inserted in the equation (4.2) and (4.3) we get

$$V_{\text{BAT\_TERM}} = \frac{3}{2} 1.21\,\text{V} \left(1 + \frac{4.3\,\text{M}\Omega}{4.7\,\text{M}\Omega}\right) \approx 3.48\,\text{V} \tag{4.4}$$

and

$$V_{\text{BAT\_SD}} = 1.21\,\text{V} \left(1 + \frac{4.3\,\text{M}\Omega}{5.1\,\text{M}\Omega}\right) \approx 2.23\,\text{V}. \tag{4.5}$$

Figure 4.5: Test environment 2 (filler)

While testing, the input voltage from the solar cells (V_{IN}), voltage of the supercap (V_{BAT}) and the output voltage (V_{SYS}) are tracked. Additionally, the illuminance (E_{v}) near the PV-cells is recorded as indicated in figure 4.6.

The purpose of the first test is to check, if the ADP5090 converts V_{IN} to a voltage $\leq V_{\mathrm{BAT\_TERM}}$. The measurements where taken over a couple hours and are plotted in Figure 4.7.

No load was connected to the output ($Z_{\mathrm{LOAD}} \rightarrow \infty$), which is the reason V_{SYS} is overlapped by V_{BAT}. It can be seen, that between 17:00 and 23:00, the super capacitor was being charged and that the ADP5090 controls the voltage V_{BAT} like expected to the adjusted maximum voltage $V_{\mathrm{BAT\_TERM}}$.

The second test should simulate the discharging when a load is connected, after the capacitor was fully charged. It was necessary to estimate the consumed power by the electronic components of the prototype. A rough measurement with a power analyser showed, that the microcontroller and the e-paper display together draw at its peak about 240 mA when connected to 5 V. The nrf52840 on the other hand, only consumes 6 mA with a 3 V source. Thus the expected consumed power at is's peak is:

$$P_e = 5\,\mathrm{V} \cdot 0.24\,\mathrm{A} + 3\,\mathrm{V} \cdot 0.006\,\mathrm{A} = 1.218\,\mathrm{W}. \tag{4.6}$$

If $Z_{\mathrm{LOAD}} = 10\,\Omega$ the load draws currents between 0.223 A and 0.348 A which again lead to a power consumption that should approximately match the power consumption of the finished prototype. Furthermore, the solar cells where covered to observe the discharging without interference of additionally charging behaviour. Figure 4.8 shows the result.

As soon as the load is connected (after 25), V_{SYS} and V_{BAT} first drop by almost 1 V and after that steadily decrease. After ca. 100 s, V_{BAT} reached the value of $V_{\mathrm{BAT\_SD}}$ and the ADP5090

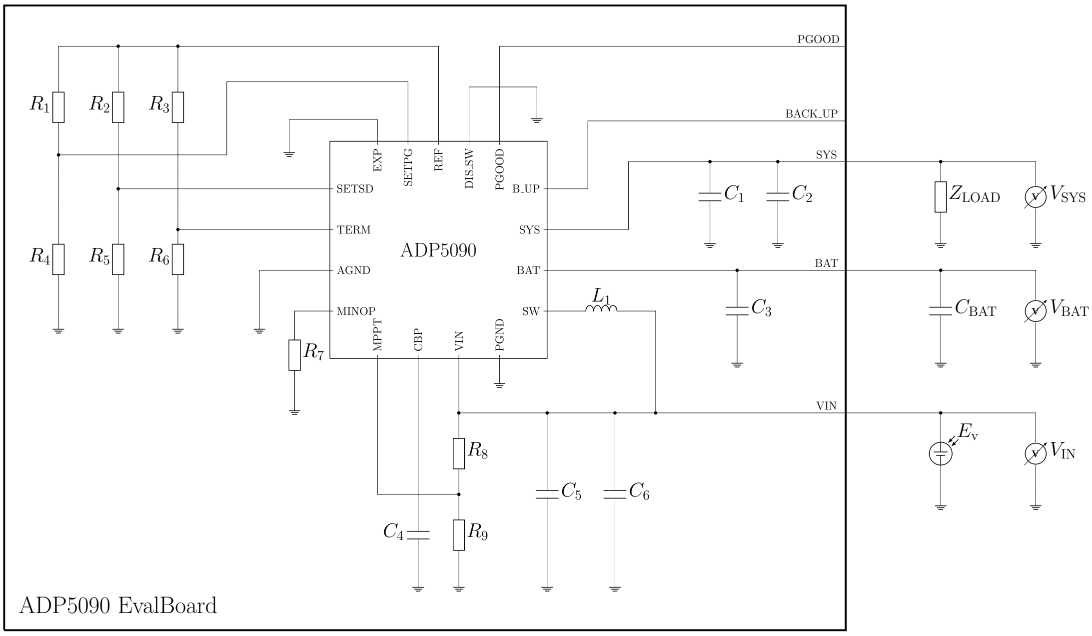


Figure 4.6: Schematics of the test setup

switches the output off (V_{SYS} drops to 0) to prevent the capacitor from overdischarging. The output now stays switched off, until V_{IN} again supplies energy, and $V_{\mathrm{BAT}} \leq V_{\mathrm{BAT\_SD}}$. It can also clearly be seen, that after 160 seconds, the ADP5090 controls V_{IN} to ca. 2.1 V. Recall that this is the optimal power point of the solar cell.

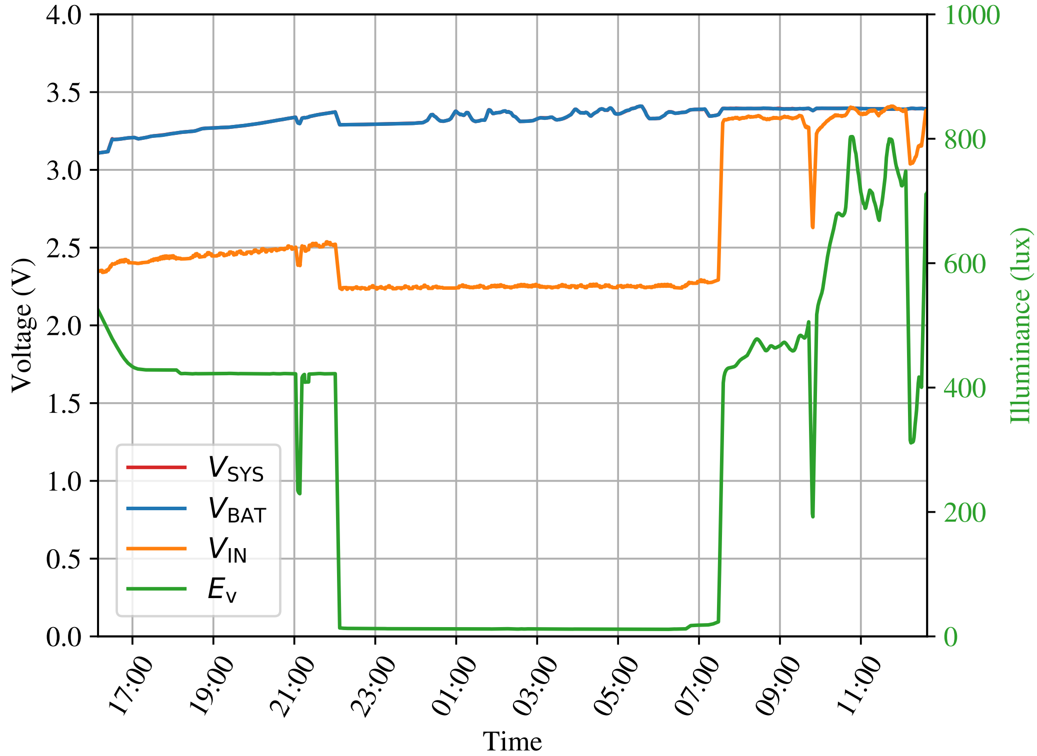


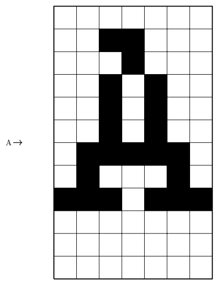
Figure 4.7: Charging behaviour

4.2 Software

-t

4.2.1 Receiver

The software of the ULPWUR is separated in three different parts.



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4.2.2 Transceiver

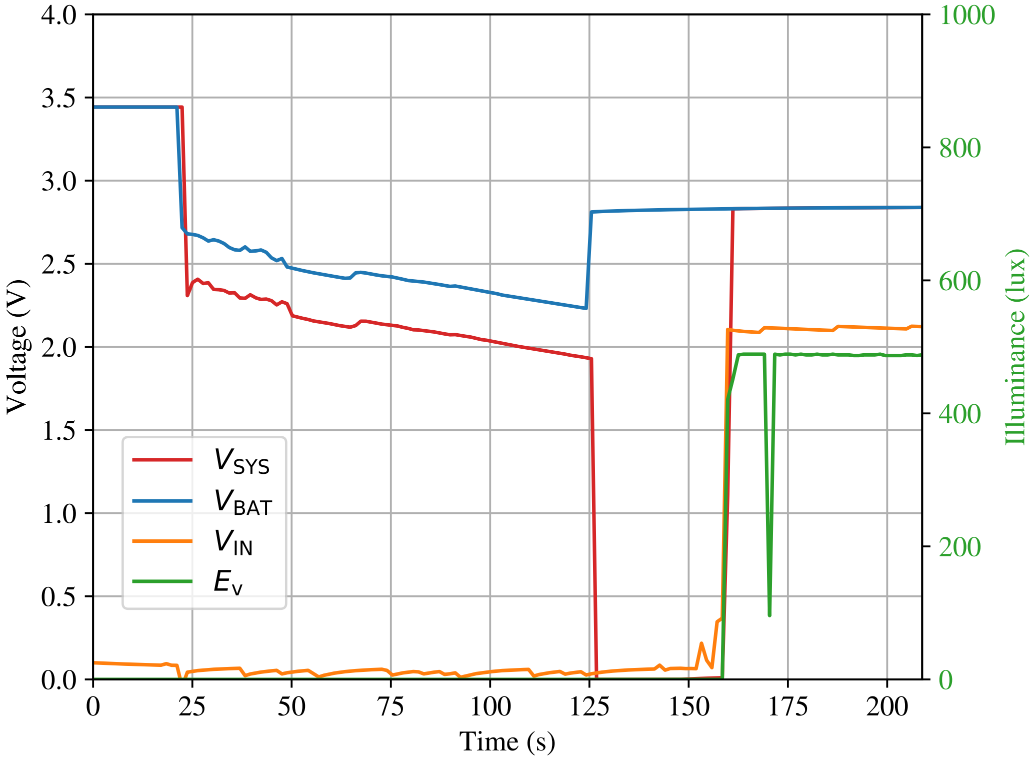

Figure 4.8: Discharging behaviour

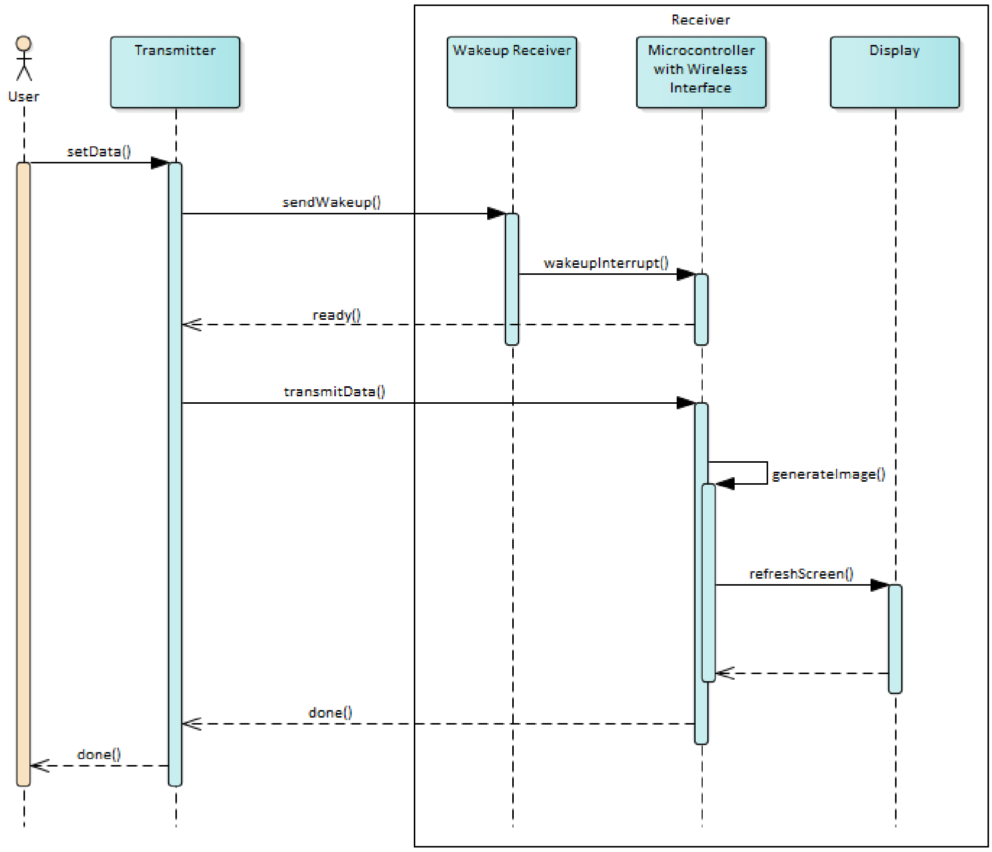

Figure 4.9: not up to date sequence

Chapter 5

Results

Chapter 6

Summary

Sources

[1] K. Amundson, *Electrophoretic Displays*. Springer International Publishing Switzerland, 2016.

[2] *AS3933 3D Low Frequency Wakeup Receiver*, Mar. 2015.

[3] *RFicient ULTRA-LOW POWER WAKE-UP RECEIVER DATASHEET (preliminary)*, 2019.

[4] *Amorphous Silicon Solar Cells*, Aug. 2019.

[5] *Ultralow Power Boost Regulator with MPPT and Charge Management*, Feb. 2017.

[6] *EVAL-ADP5090 User Guide*, 2014.

[7] *Cylinder Type Lithium Ion Capacitors*, Aug. 2019.

[8] *nRF52840 Objective Product Specification v0.5*, Dec. 2016.

[9] *STM32L4R5xx STM32L4R7xx STM32L4R9xx*, Apr. 2018.

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Statement of Plagiarism

We declare that, apart from properly referenced quotations, this report is our own work and contains no plagiarism; it has not been submitted previously for any other assessed unit on this or other degree courses.

Place	**Date**
Rapperswil	December 13, 2019

Signatures

Cedric Renda Manuel Tischhauser

Appendix A

Requirements

A.1 Assignment

HSR
HOCHSCHULE FÜR TECHNIK
RAPPERSWIL

FHO Fachhochschule Ostschweiz

Low power wakeup receiver

Semesterarbeit für Manuel Tischhauser und Cédric Renda

Herbst 2019

1. Einführung

Im Gebäudemanagement ist es üblich, Belegungspläne an den Eingängen der Räume anzubringen. Oftmals sind diese in Papierformat und müssen bei einer Änderung von Hand gewechselt werden. Mit dieser Methode werden kurzfristige Belegungen nicht aufgezeigt. Dies könnte man umgehen, wenn man mit Displays arbeitet die Wireless aktualisiert werden können. Dabei stellt sich allerdings das Problem, dass man entweder Kabel für die Netzeinspeisung verlegen muss oder Batterien verwendet, die regelmässig ersetzt werden müssen. Im Idealfall entfällt die Speisung komplett.

2. Aufgabenstellung

Zu einem Empfängermodul soll eine bidirektionale low power Kommunikationsstrecke aufgebaut werden. Der Empfänger soll durch Energy-harvesting Massnahmen möglichst passiv betrieben werden können. Dieser enthält einen Ultra Low Power Wake-up Receiver und eine Anzeige mit dem die empfangenen Daten auf entsprechende Weise dargestellt werden. Ein System kann aus mehreren Empfängern bestehen, welche unabhängig voneinander vom Sender selektiert werden können.

3. Ablauf

Zu Beginn der Arbeit sind ein Projektplan und ein Pflichtenheft zu erstellen, welche in den ersten Wochen dem Betreuer abgegeben werden müssen. Ein Vorschlag des Pflichtenheftes befindet sich im Arbeits-platzordner oder als *.docx File auf dem Public Server (\\hsr.ch\root\auw\sge\labors\Mk\pub_for_students). Planen Sie total 240 Arbeitsstunden (8 ECTS * 30 h/ECTS) ein. Die Arbeiten sollen innerhalb der Gruppe geeignet aufgeteilt werden; die Aufteilung ist im Bericht entsprechend festzuhalten, genauso wie ein Vergleich des geplanten und des effektiv durchgeführten Projektplans. Weitere Einzelheiten werden an den wöchentlichen Besprechungen festgelegt. Die Arbeiten sollen möglichst selbständig durchgeführt werden. Die Kriterien der Beurteilung und Notengebung sind im unten erwähnten Leitfaden zu finden.

4. Laborjournal

Während der Arbeit ist ein persönliches (d.h. pro Person eines), gebundenes, handschriftliches und datiertes Laborjournal zu führen. Darin werden alle Tätigkeiten betreffend Dauer und Resultate eingetragen. Ebenfalls soll darin ein Protokoll geführt werden von den wöchentlichen Treffen. Das Laborjournal wird am Ende der Arbeit abgegeben und wird mitbenotet.

5. Bericht

Über die Arbeit ist ein Bericht zu verfassen, dessen Textteil maximal 60 Seiten umfassen und eine Dateigrösse von 5MB nicht überschreiten soll. Im Bericht sollen alle gemachten Überlegungen, Abklärungen, Berechnungen und Untersuchungen detailliert (in Text und Bild) dokumentiert werden. Der Bericht muss gut leserlich geschrieben und übersichtlich gegliedert sein. Weitere Richtlinien, wie ein Bericht aufgebaut sein kann, und weitere nützliche Informationen findet man im Leitfaden, welcher in gedruckter Version im Arbeitsplatzordner und auf dem Public Server abgelegt ist.
Des Weiteren muss im Bericht unbedingt eine unterschriebene Nicht-Plagiatserklärung enthalten sein, ein Beispiel dieser Erklärung befindet sich auf dem Public Server.
Der Bericht ist in 1 Papier-Exemplar abzugeben, mit einer beiliegenden CD-ROM, auf der alle anfallenden Daten, wie auch der Bericht selbst (im PDF-Format) gespeichert sind.

Writing in English is highly encouraged.

6. Termine

Beginn der Arbeit:
Abgabe des Berichts:
Mündliche Präsentation:

7. Organisatorisches

Betreuung der Arbeit:	
Betreuung des Labors:	
Arbeitsplatz:	
Industriepartner:	
Besprechungen:	wöchentlich, nach Vereinbarung, an der HSR
Examinator:	Prof. Dr. Heinz Mathis, hmathis@hsr.ch

Rapperswil, [Datum]

Viel Erfolg wünscht Ihnen

Heinz Mathis,
Dozent Mobilkommunikation

A.2 Requirement Specification

HSR
HOCHSCHULE FÜR TECHNIK
RAPPERSWIL

FHO Fachhochschule Ostschweiz

Pflichtenheft

Projekt: Low power wakeup receiver

Version 0.1

Cédric Renda, Manuel Tischhauser

Name	Datum	Unterschrift
Prof. Dr. Heinz Mathis		
Selina Malacarne		
Cédric Renda		
Manuel Tischhauser		

27. September 2019

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1 Einleitung

Im Gebäudemanagement ist es üblich, Belegungspläne an den Eingängen der Räume anzubringen. Oftmals sind diese in Papierformat und müssen bei einer Änderung von Hand gewechselt werden. Mit dieser Methode werden kurzfristige Belegungen nicht aufgezeigt. Dies könnte man umgehen, wenn man mit Displays arbeitet, die über eine drahtlose Schnittstelle aktualisiert werden können. Dabei stellt sich allerdings das Problem, dass man entweder Kabel für die Netzeinspeisung verlegen muss, oder Batterien verwendet, die regelmässig ersetzt werden müssen. Im Idealfall entfällt die Speisung komplett.

2 Auftrag

Im Rahmen dieser Semesterarbeit soll eine Lösung zur oben beschriebenen Problematik ausgearbeitet werden. Der Fokus liegt auf der Erstellung eines autarken Anzeigesystems welches über eine drahtlose Schnittstelle bedient werden kann. Die folgende Punkte sollen dabei abgearbeitet werden:

- Recherche bezüglich Schnittstelle und Energy Harvesting.
- Vor- und Nachteile bestehender Technologien abwägen und geeignete Hardware wählen.
- Erstellen eines lauffähigen Prototypen.

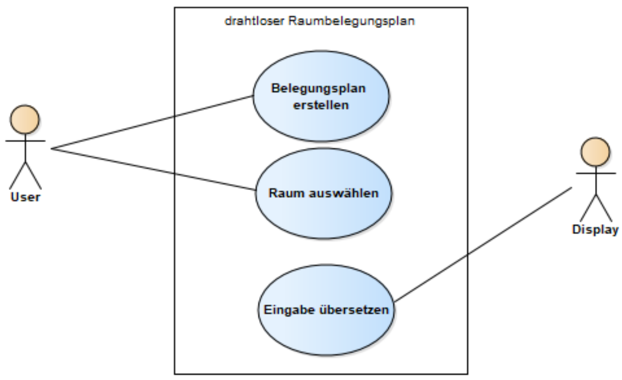


Abbildung 2.1: *Use-Case Diagramm*

Der Prototyp richtet sich nach dem Use-Case Diagramm in Abbildung 2.1.

3 Produktanforderungen

Das Empfängermodul ist autark und kann auf einem Display Stundenpläne anzeigen. Diese werden über eine drahtlose, bidirektionale Schnittstelle gesendet. Der Sender wird mit einem Computer bedient.

Besteht das System aus mehreren Empfängern, so kann das Sendemodul diese unabhängig voneinander selektieren.

3.1 Hardware

Sender

- Schnittelle zum Computer
- Sendemodul

Empfänger

- Mikrocontroller oder Vergleichbares (Prozessor, Speicher, usw.)
- E-Paper-Display
- Energy-Harvesting-Einheit
- Energiespeicher
- Empfangsmodul

3.2 Software

Sender

- Treiber für Sendemodul

Empfänger

- Firmware für Mikrocontroller

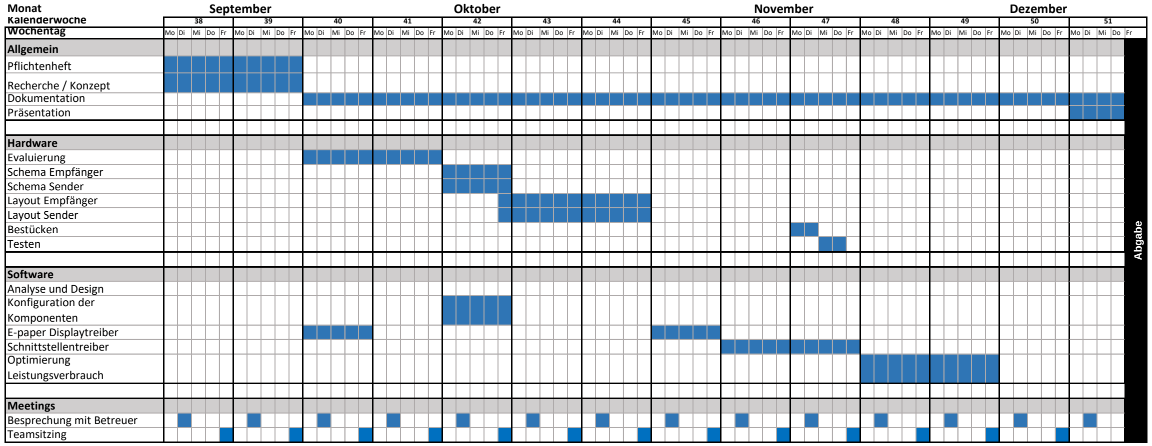
3.3 Varianten/Optionen

Ist der Prototyp funktionsfähig, soll zu einem späteren Zeitpunkt auch möglich sein, verschiedene Bildschirmgrössen zu verwenden, wobei sich auch Anzeige nicht nur auf Raumbelegungspläne beschränkt. Deshalb soll das System und insbesondere die Software so flexibel wie möglich entwickelt werden.

3.4 Dokumentation

Die Dokumentation beinhaltet sämtliche Überlegungen, Abklärungen, Berechnungen und Untersuchungen, welche im Laufe der Semesterarbeit gemacht wurden.

4 Zeitplan


Monat
Kalenderwoche
Wochentag
September
Oktober
November
Dezember
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Allgemein
Pflichtenheft
Recherche / Konzept
Dokumentation
Präsentation
Hardware
Evaluierung
Schema Empfänger
Schema Sender
Layout Empfänger
Layout Sender
Bestücken
Testen
Software
Analyse und Design
Konfiguration der Komponenten
E-paper Displaytreiber
Schnittstellentreiber
Optimierung Leistungsverbrauch
Meetings
Besprechung mit Betreuer
Teamsitzing
Abgabe