Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

CENTER FOR PROJECT-BASED LEARNING

DEPARTMENT OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING

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# Fusion of BLE Direction Finding & UWB Ranging for Indoor Localization

Semester Thesis

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# Acknowledgements

I would like to begin this report by thanking several people who helped me greatly during this semester project. Firstly I would like to thank my two supervisors Dr. Michele Magno and Silvano Cortesi Msc, for their support and guidance during this project. I would also like to thank Dr. Christian Vogt, Elio Reinschmidt Bsc, Federico Villani Bsc and Lukas Schulthess Msc for their knowledge and support in embedded IoT design and the Zephyr RTOS.

# Abstract

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

The **abstract** is the presentation card of your work, it is fundamental to describe your contribution and relevant results in few lines of text. It must fit in one page and should include:

- Short description of your topic or use case;
- Short description of existing technology, work, product and the scientific research challenges still unsolved;
- Description of you work and your contribution;
- A short summary of the most relevant results of your work and the conclusions you draw from it.

# Declaration of Originality

I hereby confirm that I am the sole author of the written work here enclosed and that I have compiled it in my own words. Parts excepted are corrections of form and content by the supervisor. For a detailed version of the declaration of originality, please refer to Appendix B

Nando Galliard Bsc,
Zurich, April 2022

# Contents

# List of Figures

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# List of Acronyms

AA . . . . . . . . Access Address
AAAAA . . . . . WHATISIT
AES . . . . . . . Advanced Encryption Standard
ASIC . . . . . . Application-Specific Integrated Circuit

CRC . . . . . . . Cyclic Redundancy Check
CTE . . . . . . . Constant Tone Extension

DES . . . . . . . Data Encryption Standard
DVI . . . . . . . Device Independent File Format

ECC . . . . . . . Elliptic Curve Cryptography
ECDSA . . . . . Elliptic Curve Digital Signature Algorithm
EPS . . . . . . . Encapsulated PostScript

FPGA . . . . . . Field Programmable Gate Array

IC . . . . . . . . Integrated Circuit
IIS . . . . . . . . Integrated Systems Laboratory

LED . . . . . . . Light-Emitting Diode

NIST . . . . . . National Institute of Standards and Technology

PDF . . . . . . . Portable Document Format

PDU . . . . . . . Protocol Data Unit / Payload of BLE

WYSIWYG . . . What You See Is What You Get

Chapter 1

# Introduction

Give an overview of the problem, and put your work into a bigger context. Motivate the questions addressed in this work and summarize your contributions.

## 1.1. Motivation

Give a broader context on why your thesis is important, what problem is solved by it, why is it needed, ....?

## 1.2. Objective

what was the objective of your thesis? also add your research questions here

### 1.2.1. Research Questions

1. first research qestion...
2. second reserach question...

### 1.2.2. Outline

At the end of this chapter, give an outline and describe the organization of your thesis

# Chapter 2

# Related Work

Describe relevant aspects of related work, make sure to have a good covering of your approach/design with others who did similar things. You will need to compare this related work with your results in the Discussion chapter. We expect a lot of citations [3] here.

Make sure to also give the results of the related work relevant to your thesis presented here, including numbers. Often, at the end of this section an overview table makes sense, where you compare related work for different aspects related to your own thesis.

## 2.1. Indoor tracking technologies

## 2.2. Algorithms for localisation

# Chapter 3

# Theory / Background

## 3.1. Bluetooth Low Energy Localisation

Bluetooth is a widely available and broadly used short-range communication protocol. Bluetooth low energy (BLE) is a variant of this protocol that was introduced by the Bluetooth Special Interest Group (SIG) with Bluetooth v4.0 intended for edge devices with steeper energy consumption requirements. BLE uses the industrial, scientific and medical (ISM) band at 2.4 GHz which gets divided into 40 2 MHz channels. In contrast Bluetooth itself uses 79 1 MHz channels at the same frequency band. [4][5] During a connection the devices use 37 of the available channels with adaptive frequency hopping while the remaining three channels are dedicated to advertising. With Bluetooth v5.0 and extended advertising all 40 radio channels are used. For one localisation connection with BLE there are two roles. One stationary anchor where the location is known and one beacon that has yet to be located.

### 3.1.1. Received Signal Strength Indicator

The original way of of estimating ones location with BLE. RSSI estimates the distance of the beacon from the anchor by performing a path loss calculation on the received signal strength, hence the name. This signal strength loss over distance is heavily reliant on the chipset vendors and difference in radio circuits. Additonally RSSI is reliant on a path-loss model suited to each location. Thus in general RSSI offers only a rough distance estimation in the range of multiple meters. [6] With the deployment of multiple known anchors over the desired are one can localize a Bluetooth device by means of trilateration. This approach of the trilateration is not not suited for this work and will thus not be further discussed.

### 3.1.2. Angle Of Arrival

With the release of Bluetooth Core Specification v5.1 support was added for a new high-accuracy direction finding of a single received radio signal via a connected antenna array. With angle of arrival (AoA) the transmitter sends a special prolonged direction finding signal, explained in chapter **??**, which gets IQ sampled by a receiver equipped with multiple antennas as seen in figure 3.1. The angle $\Theta$ can be calculated with the known frequency of the radio signal and thus the wave length $\lambda$ and the distance $d$ between the antennas. As shown for two dimensions in equation 3.1 [7].

$$\Theta = arccos\left(\frac{\phi \cdot \lambda}{2 \cdot \pi \cdot d}\right) \tag{3.1}$$

One needs to take in to account that the maximum distance of all antennas in an array needs to be compressed into one wavelength. The complete collection process and subsequent calculation of the angle in 3D space is not part of this work since prefabricated units were employed that feature built-in computation units.

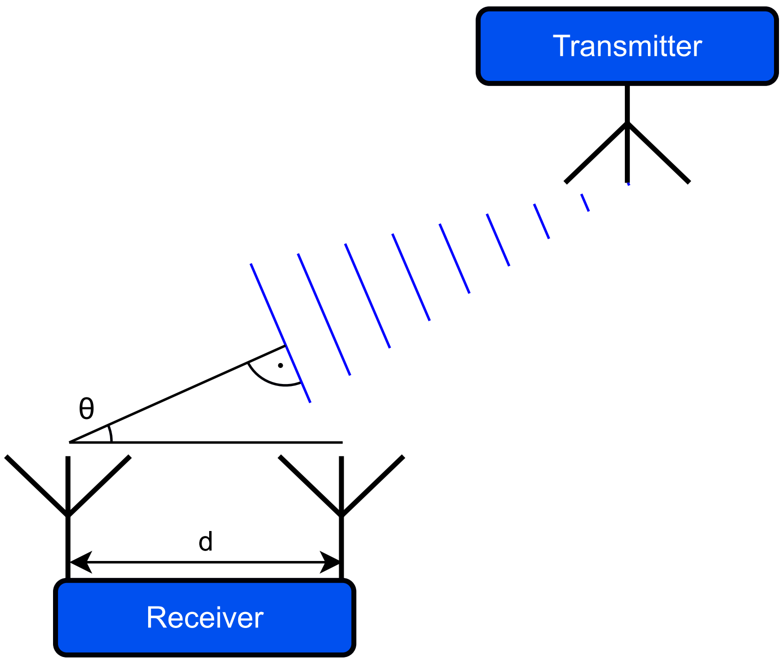


Figure 3.1.: AoA exemplar. Array at receiver. Blue lines represent radio signal.

### 3.1.3. Angle Of Departure

With angle of departure (AoD) the roles are reversed and the static anchor utilises a single antenna while the mobile beacon is equipped with an antenna array as seen in figure 3.2. By IQ sampling the incoming radio signals from all the antennas and their distance $d$ to each other the anchor can discern the phase changes $\phi$ between the signals from which it calculates the angle of departure $\Theta$ as shown for two dimensions in equation 3.2 [7].

$$\Theta = arcsin\left(\frac{\phi \cdot \lambda}{2 \cdot \pi \cdot d}\right) \tag{3.2}$$

This technique is desirable when the location of one single beacon needs to be as reliable as possible, since the anchors can be numerously and cheaper deployed while the more expensive beacon uses the antenna array. We will not discuss this direction finding method further in this work since our aim is to provide for as many beacons while keeping the cost per beacon as low as feasible.

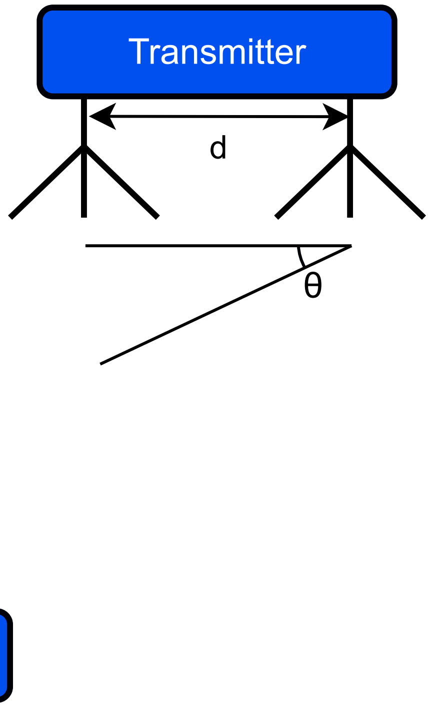


Figure 3.2.: AoD exemplar. Array at transmitter. Blue lines represent radio signal.

### 3.1.4. Bluetooth Direction Finding Signals

For ease of use the packages in Bluetooth have the same structure for advertisements and for data transmission. The packet consists of four components as shown in figure 3.3. The preamble is an alternating set of ones and zeroes used for frequency synchronisation, automatic gain control training and symbol timing estimation. In essence to tune the

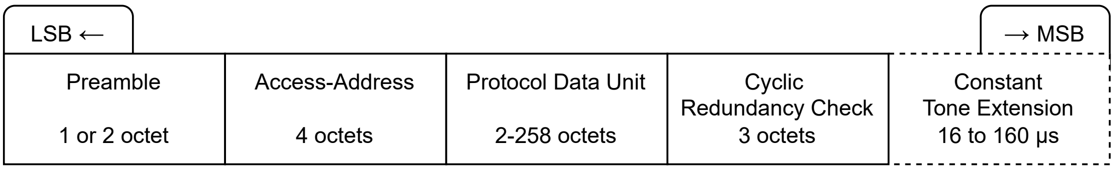


Figure 3.3.: Bluetooth direction finding signal with constant tone extension.

receiver. Secondly the access address is sent. Each connection between two devices has a distinct address used to distinguish the transmission. Thirdly the protocol data unit (PDU) gets sent which includes the length of the payload and the payload itself. Lastly a redundancy check (CRC) is calculated from the PDU to guarantee correct transmission of the payload. If the payload is encrypted the CRC gets calculated after encryption. [8]

Direction finding signals from BLE are classic Bluetooth link layer packets with a constant signal added at the end, a so called constant tone extension (CTE). Bluetooth sends data via frequency modulation by adding or removing a value defined as frequency deviation $\Delta f$. When the channel frequency is defined as $F_{CH}$ a information bit equal to one is sent at frequency $F_{CH} + \Delta f$ and respectively a zero is sent at $F_{CH} - \Delta f$. Consequently changing the frequency also changes the wavelength which is essential to calculating the angle of arrival as seen in chapter 3.1.2. Thus the CTE is defined as only digital ones to guarantee the transmission is sent at one frequency and hence the wavelength does not change over the sampling period.

### 3.1.5. Bluetooth Advertisements

The antenna array boards designed by U-Blox only accept transmissions that get advertised with the Eddystone protocol [?] that was designed by Google to specifically be used for proximity beacon messaging that can be sent in the payload of a Bluetooth message. In total there are four different frame types for different use cases like broadcasting simple (UID) or encrypted identification (EID), url or website addresses (URL) or telemetry information (TLM).

To satisfy the filter of the U-Blox anchor employs only the simple identification frame designated UID is necessary. Figure **??** shows the complete structure of the advertisement frame that the This frame has a size of 20 Bytes. Not yet done. Brain empty
I
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I
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| Country | Frequency Bands with restrictions | FB without restrictions |
|---|---|---|
| Europe | 3.1–4.8 GHz | 6–8.5 GHz |
| North America | - | 3.1–10.6 GHz |
| Japan | 3.4–4.8 GHz | 7.25–10.2 GHz |
| Korea | 3.4–4.8 GHz | 7.2–10.2 GHz |
| Singapore | 6–9 GHz | 3.4–4.2 GHz |

Table 3.1.: UWB frequency band standards utilised in different regions. [2]

## 3.2. Ultra Wide Band Ranging

Ultra wide band (UWB) is another radio technology specialising in low energy consumption, high-bandwidth and short-range transmissions. The UWB standards frequency band is not static and restricted by local laws as shown in Table 3.1 which displays the worldwide differences in frequency bands utilised by UWB. One can see that UWB occupies a wide range in bandwidths thus it must be able to coexist with other narrow-band signals (TV, GPS, GSM, UMTS/3G, etc). To achieve no intolerable interference for other radio technologies UWB uses a wide bandwidth range but with low emission and intensity below the power floor of other radio signals. Thus UWB is able to share the specrum with existing services. [9]

### 3.2.1. Distance Measurement Techniques With UWB

While Bluetooth has RSSI which enables distance calculation between two devices its precision is in the range of multiple meters. This is where UWB comes in with time of flight distance calculations. There are two different ways to measure the distance between different UWB actors. This subsection aims to present an overview over the different techniques and which ultimately will be used in this report.

### 3.2.2. Double-sided two-way ranging

In double-sided ranging you have a designated initiator (Beacon) and likewise a designated responder (Anchor). The initiator starts the measurement exchange by broadcasting a poll frame via UWB and recording the transmission time-stamp (TX1) and then waits a limited time for a response message. When a responder receives this poll frame its own reception time-stamp (RX1) is recorded and it sends a reception frame back to the initiator containing only an activity code to go on with the ranging exchange. The initiator receives this message and records its reception time-stamp (RX2) predicts when the final transmission (TX2) will have been send and sends with the final message the time-stamps TX1, TX2 and RX2. The responder is then able to work out the estimated distance between the two devices from these four timestamps by knowing the time of flight over the air and this equation 3.3. Notice the factor $F_{UUS} = f_C \cdot N$ which incorporates the clock cycle $f_C$ of the antenna chip and the sampling number per clock pulse $N$ for the internal time register. After the ranging exchange is done only the responder has knowledge of the distance calculated.

$$d\{m\} = \frac{RX1 * RX2 - TX1 * TX2}{RX1 + RX2 + TX1 + TX2} * F_{UUS} * c \tag{3.3}$$

### 3.2.3. Single-sided two-way ranging

In single-sided ranging the initiator ends up with the calculated distance and incorporates one message less than double-sided ranging. It begins by sending a polling frame and recording its transmission timestamp (TX1). The responder answers with a response frame containing the responders reception (RX1) and transmission time-stamp (TX2). The initiator records the last reception time-stamp (RX2) and calculates with equation 3.3 the estimated distance. This technique suffers poorer accuracy due to the clock offset between the two actor nodes and this clock offset needs to be recorded and taken into account to increase precision.

We wanted a beacon that announces his presence when expected but can be put to sleep if not needed. For this reason and the accuracy loss of single-sided ranging we went with the double-sided two-way ranging setup where the initiator is the mobile beacon.

### 3.2.4. IEEE Standard 802

TODO

## 3.3. Weighted averaging of location data

Probs doesn't need to be explained here.

# Chapter 4

# Zephyr

## 4.1. RTOS Operating system

The Zephyr OS is a real time operating system based on a small-footprint kernel not too dissimilar to unix for use on resource-constrained embedded systems like internet of things edge devices. It supports multiple architectures and is licensed under Apache 2.0 [10].

## 4.2. External Module Instruction

When one wants to add an own implementation of a zephyr board or driver one generally adds it into the zephyr root itself. While being the easiest implementation it hinders version control when working in groups or with multiple branches, since a project can't be pushed to zephyr main.

Zephyr has an implementation for this called modules that can be added on compilation from an out of (zephyr) tree folder. While the wiki is comprehensive it still took some work to figure out and nobody at PBL worked with this technique before thus we are adding this chapter as a guide for future use. Find the folder structure in subsection 4.2.1.

### 4.2.1. Folder Structure

The best way to start with a custom board is to take the corresponding development board and change its pin connections in the .dts file. A shield can be seen as a modification of the original .dts board file. This application *app* incorporates a custom board *foo* a additional shield *egg_bar* and a module *foobar*. The file content for all relevant files is located in appendix E. We employed two environment variables, PROJECT_ROOT gives the path to the project root folder and ZEPHYR_BASE gives the path to the zephyr install location which should already be created by the zephyr install.

```
/project_root
├── app ............................................ Application folder.
│   ├── src ........................................ Source folder for C code.
│   │   └── main.c ................................. Sample main file.
│   ├── CMakeList.txt .............................. CMake file partially listed above.
│   └── prj.conf ................................... Project configuration.
├── boards ......................................... The custom board folder.
│   ├── arm ........................................ CPU architecture that the main chip hails from.
│   │   └── foo .................................... Folder of custom board called foo.
│   │       ├── doc ................................ Optional: Some documentation.
│   │       ├── foo.dts ............................ Device tree script of board.
│   │       ├── foo_defconfig ...................... Mandatory Kconfig flags for this board.
│   │       ├── foo.yaml ........................... Description of chip and supported protocols.
│   │       ├── board.cmake ........................ Runner arguments for debugger.
│   │       ├── CMakeList.txt ...................... Adding of library and sources from this folder.
│   │       ├── Kconfig ............................ Board configuration parameters definition.
│   │       ├── Kconfig.board ...................... Configuration parameters to activate board.
│   │       └── Kconfig.defconfig .................. Board configuration parameters definition.
│   └── shields .................................... Location for any shields.
│       └── egg_bar ................................ Folder of shield called bar by company egg.
│           ├── doc ................................ Optional: Some documentation.
│           ├── egg_bar.overlay .................... Overlay to .dts of boardfile.
│           ├── Kconfig.shield ..................... Check if shield is activated in Kconfig.
│           └── Kconfig.defconfig .................. Shield configuration parameters necessary.
└── modules ........................................ The custom board folder.
    ├── foobar ..................................... Name of custom module.
    │   └── zephyr ................................. module.yml needs to be in zephyr folder!
    │       ├── driver ............................. Driver folder.
    │       │   └── driver.c ....................... Driver c file.
    │       ├── dts ................................ Device tree folder.
    │       │   └── bindings ....................... Modules need bindings to devicetree.
    │       │       ├── egg ........................ Vendor name.
    │       │       │   └── egg,foobar.yaml ........ Properties needed for module.
    │       │       └── vendor-prefixes.txt ........ Optional: Some documentation.
    │       ├── CMakeList.txt ...................... Folder of custom board called foo.
    │       ├── kconfig ............................ Folder of custom board called foo.
    │       └── module.yml ......................... Descriptor of module foobar.
    └── modules.cmake .............................. Adds cmake and Kconfig flags for all modules.
```

Chapter 5

# Hardware / Firmware / Algorithm Implementation

Chapter 6

# Implementation Of Localisation Beacon & Anchor

## 6.1. Bluetooth Anchor

The Bluetooth anchor consists of the C211 antenna board from the XPLR-AOA-2 evaluation kit of the company U-Blox visible in figure 6.1. It is equipped with an array of five Bluetooth antenna plates arranged in an rectangular fashion compatible with Bluetooth v5.1 and designed for angle of arrival localisation described in section 3.1.2. It also boasts a NINA-B411 Bluetooth module also from U-Blox that directly calculates the azimuth and elevation angle of a broadcasting beacon relative to the beacon ground plane visible in figure 6.2 and outputs these findings over Serial USB. Classically this antenna board is intended to be used with at least three other C211 boards and a C209 beacon board that then gets triangulated. The firmware for the C211 boards is closed source and can only marginally be configured by preprogrammed commands to for example only accept beacon signals with certain classifications [1]. The corresponding beacon boards C209 on the other hand are open source [11] and a custom implementation can thus be designed.

## 6.2. Custom Beacon Board

The hardware design of the beacon board was done in an earlier project by Silvano Cortesi Msc who is one of the supervisors of this thesis. The complete schematic for this board is in the appendix D. The goal with this board was to include UWB radio in the same housing that was used with the original C209 boards while maintaining the liberty of battery powered freedom, USB enabled recharging and Bluetooth v5.1 radio connections.

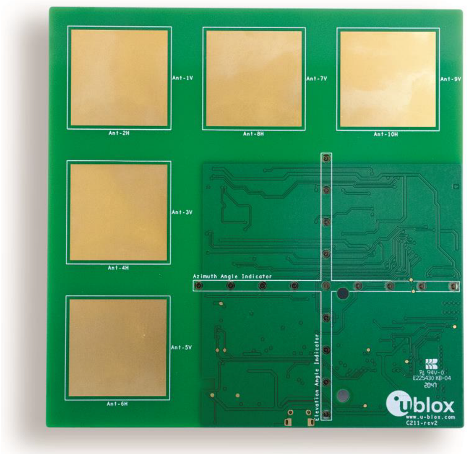

Figure 6.1.: C211 board from U-Blox [1]

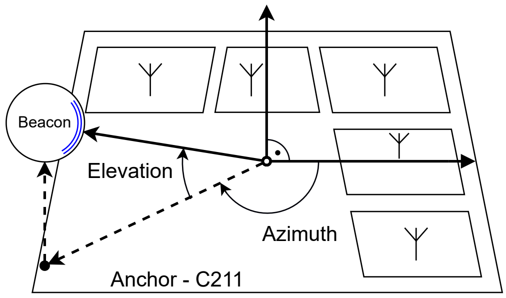


Figure 6.2.: El & Az angles TODO

### 6.2.1. MCU And Radio

The beacon boards MCU is a U-Blox stand-alone dual-core low energy module equipped with Bluetooth v5.2 and IEEE 802.15.4 adequate 2.4 GHz radio [12]. It is based on the Nordic Semiconductor nRF5340 system on chip (SoC) with an ARM Cortex-M33 application and additional network processor. The nRF5340s application core runs at 128 or 64 MHz and is equipped with 1 MB of flash memory and 512 kB of RAM. The network core on the other hand only runs at a maximum of 64 MHz and has 256 kB flash memory and 64 kB RAM. At 3V supply voltage and core benchmark tests running the application core consumes 62.5 $\mu A/MHz$ at full 128 MHz clock speed while the network core consumes 40.6 $\mu A/MHz$ at full 64 MHz. The whole module is seated in a 48 pin ball grid array package.

### 6.2.2. UWB Module

To utilise UWB radio on this new board it is equiped with the Qorvo (formerly Decawave) DWM3000 [13] fully integrated ultra-wideband transceiver module which itself is based on the DW3110 integrated circuit (IC). It integrateds an antenna, RF circuitry, power managment and clock circuitry in the module which makes integration simpler. It is IEEE 802.15.4-2015 compliant and supports UWB Channels 5 (6.5 GHz ± 500MHz) and Channel 9 (8 GHz ± 500MHz). Lastly it is controlled via a SPI interface to the host processor.

### 6.2.3. Utilities

Additionally the board incorporates a battery pack with the size jet to be determined with on board battery monitor and a system in package 3D accelerometer and 3D digital gyroscope with the LSM6DSV16X [14] by ST Microelectronics.

## 6.3. Layout

Chapter 7

# Firmware Of Beacon And Anchor

The firmware of the

## 7.1. Threads

## 7.2. BLE Package Implementation

## 7.3. UWB Handshake

## 7.4. Coordinate Transformations

Do I really need this chapter? Lol

# Chapter 8

# Results

First describe your measurement setup and settings (so it could be reproduced) and afterwards describe the results you got from your experiments. Putting results in perspective and interpretation do not belong in this chapter (put that into the discussion)

## 8.1. Method

experimental setup, used hardware and software, etc. Always rename this section appropriately, e.g. *Range measurement setup.*

## 8.2. Results with Method 1

Give the results obtained with the previously described method, rename when usefull, e.g. *Range measurement results.*

## 8.3. Experimental Setup for Distance Measurements

## 8.4. Results For Distance Measurements

## 8.5. Experimental Setup For Angle Measurements

## 8.6. Results For Angle Measurements

## 8.7. Experimental Setup For Combined Measurements

## 8.8. Results For Combined Measurements

# Chapter 9

# Discussion

Draw your conclusions from the results you achieved and summarize your contributions. Comparisons (e.g., of hardware figures) with related work are also appropriate here. Point out things that could or need to be investigated further.

# Chapter 10

# Conclusion and Future Work

Short chapter on the conclusions you can draw from your work, and what is still to be done (and what contributions the students after you could make).

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Task Description for a Semester Thesis on

# Fusion of BLE Direction Finding and UWB Ranging for Indoor Localization

at the Departement of Information Technology and
Electrical Engineering

for

**Nando Galliard**
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| | |
|---|---|
| **Advisors:** | Silvano Cortesi, silvano.cortesi@pbl.ee.ethz.ch |
| **Professor:** | Prof. Dr. Luca Benini, lbenini@iis.ee.ethz.ch |
| **Handout Date:** | 14.02.2022 |
| **Due Date:** | XX.04.2022 |

## Project Goals

Bluetooth Low Energy (BLE) Direction Finding is a novel technology added to the Bluetooth Specification with the aim to use BLE for Indoor Localization. It specifies an addition to the protocol to support angle of arrival (AoA) as well as angle of departure measurements (AoD). As no reliable distance measurement for BLE is available yet, for a precise localization there is need for at least three anchor nodes with each multiple antenna arrays. Ultra wideband (UWB) is on the other hand a well known protocol used for Indoor Localization using different ranging methods and performing then a trilateration with at least three nodes.

If we are able to combine these two methods on a single anchor, getting angle of arrival as well as distance data, we are able to perform Indoor Localization with a single anchor.

Thus the aim of this thesis is to

- acquire angle of arrival informations using BLE Direction Finding
- acquire distance informations using UWB
- combine the two informations in order to perform a localization
- evaluate the performance of the system

## Tasks

The project will be split into three phases, as described below:

### Phase 1 (Week 1)

1. Investigate the state-of-the-art of the single blocks (BLE Direction Finding, UWB Ranging).
2. Study and get used to the hardware and the tools to program, i.e. microcontroller programming using Zephyr, provided PCB, . . . .
3. The main aim of this phase is to get used to Zephyr and the used technologies.

### Phase 2 (Week 2-3)

1. Integration of the DWM3000 drivers to Zephyr
2. Creating two applications using Zephyr which
   a) Perform two-ways ranging with an UWB base node
   b) Advertise an Eddystone beacon containing the constant tone extension for BLE Direction Finding
3. Merge the two applications into a single one

### Phase 3 (Week 4-5)

1. Evaluate and characterize the performance of the two measurements separately
2. Implement a simple algorithm to fuse the two measurement data (provided by Silvano Cortesi)
3. Evaluate and characterize the performance of the sensor fused system.

### Phase 4 (Week 6-7)

1. Finalize evaluation of the system
2. Writing of the report
3. Creation of the presentation

## Milestones

By the end of **Phase 1** the following should be completed:

- Gained knowledge about the used technologies (BLE Direction Finding, UWB Ranging)
- Know how the Zephyr system works and how to use it in order to
  - Create new board files for a custom PCB
  - Add a driver/module to the Zephyr ecosystem
  - Create an (out-of-tree) application using the Zephyr ecosystem

By the end of **Phase 2** the following should be completed:

- The driver for the DWM3000 should be integrated into Zephyr
- A finalized application should be created, providing the tag node with the capabilities for BLE Direction Finding as well as UWB Ranging

By the end of **Phase 3** the following should be completed:

- The UWB Ranging / distance measurement should be evaluated and characterised
- The BLE Direction Finding / angle measurement should be evaluated and characterised
- The combined system should be evaluated and characterised

By the end of **Phase 4** the following should be completed:

- Final design and last in-field tests
- Final report and presentation

## Project Organization

### Weekly Report

There will be a weekly report sent by the candidate at the end of every week. The main purpose of this report is to document the project's progress and should be used by the student as a way to communicate any problems that arise during the week.

### Project Plan

Within the first weeks of the project, you will be asked to prepare a project plan. This plan should identify the tasks to be performed during the project and sets deadlines for those tasks. The prepared plan will be a topic of discussion of the first week's meeting between you and your advisers. Note that the project plan should be updated constantly depending on the project's status.

### Final Report and Paper

PDF copies of the report are to be turned in. References will be provided by the supervisors by mail and at the meetings during the whole project.

### Final Presentation

There will be a presentation (15 min presentation and 5 min Q&A for BT/ST and 20 min presentation and 10 min Q&A for MT) at the end of this project in order to present your results to a wider audience. The exact date will be determined towards the end of the work.

### References

Additional references will be provided by the supervisors by mail and at the meetings during the whole project.

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Swiss Federal Institute of Technology Zurich

## Declaration of originality

The signed declaration of originality is a component of every semester paper, Bachelor's thesis, Master's thesis and any other degree paper undertaken during the course of studies, including the respective electronic versions.

Lecturers may also require a declaration of originality for other written papers compiled for their courses.

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I hereby confirm that I am the sole author of the written work here enclosed and that I have compiled it in my own words. Parts excepted are corrections of form and content by the supervisor.

**Title of work** (in block letters):

FUSION OF BLE DIRECTION FINDING AND UWB RANGING FOR INDOOR LOCALIZATION

**Authored by** (in block letters):
*For papers written by groups the names of all authors are required.*

| **Name(s):** | **First name(s):** |
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With my signature I confirm that
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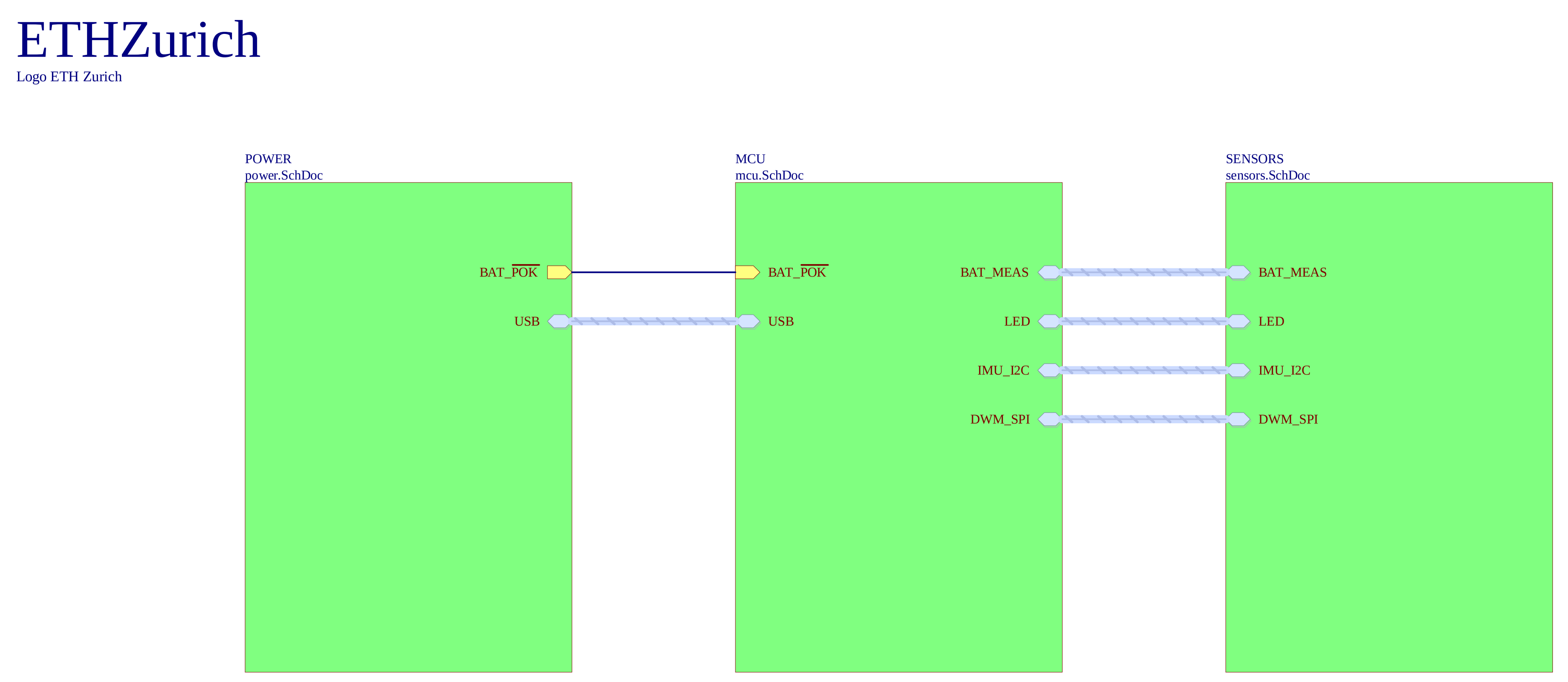
# Appendix C

# File Structure

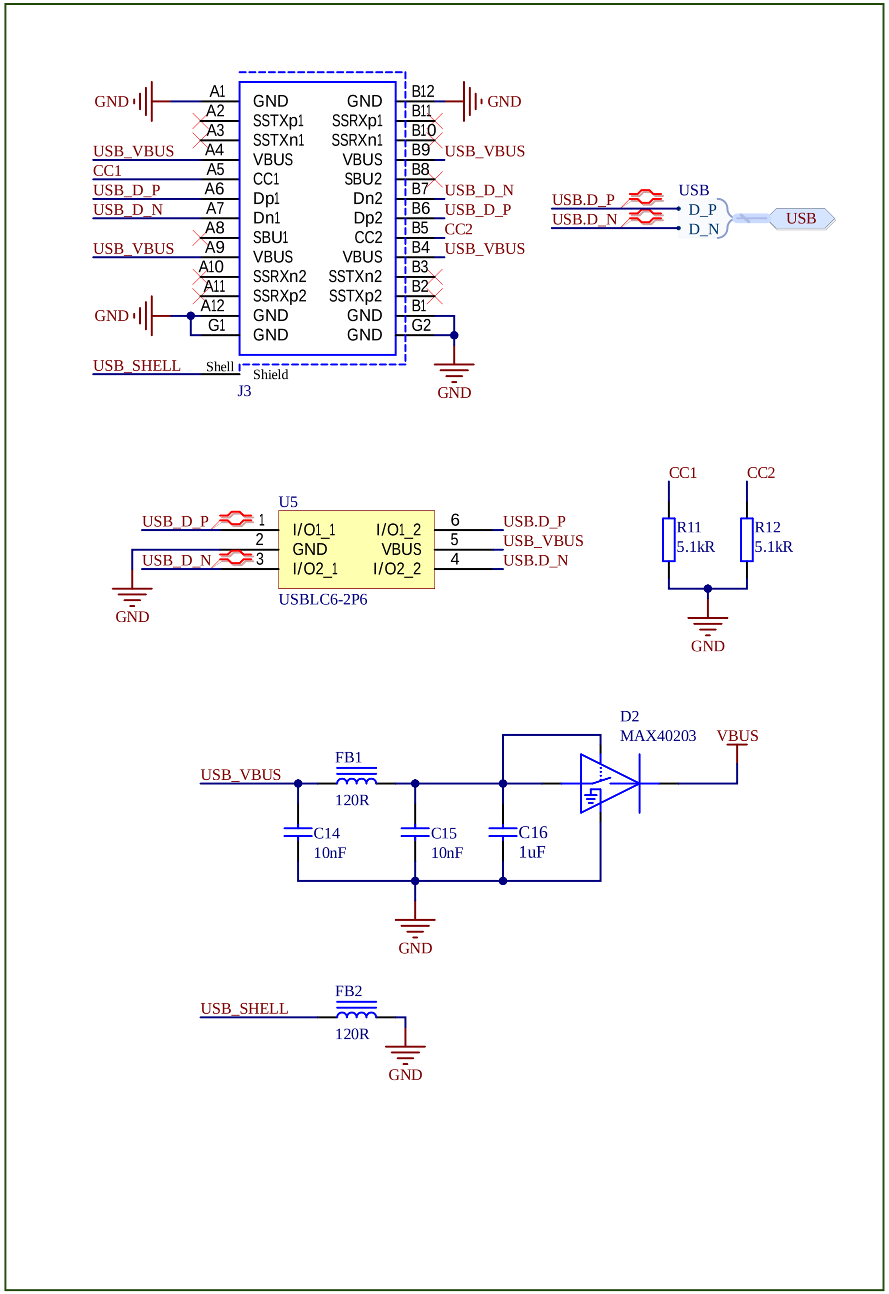
In this chapter we give a overview over the project git directories and files.

/
- `README` ......... A README with some general information about the project.
- `01_report` ............................. The source files of the project report.
- `02_presentation` ......................... The source files of the presentation.
- `03_designflow` ................................ Some designflow-specific files.

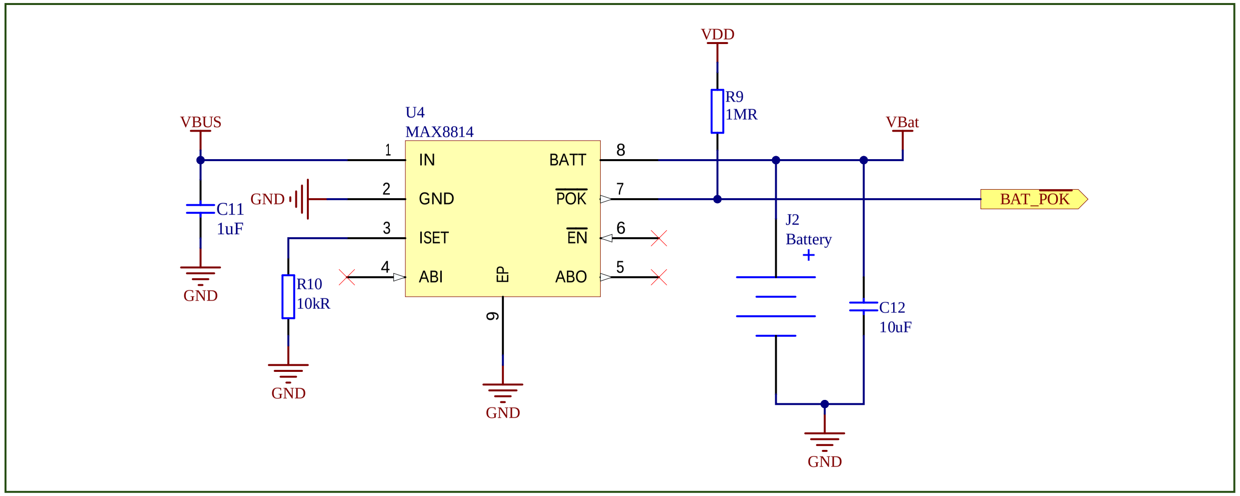



| | | | |
|---|---|---|---|
| Eidgenössische Technische Hochschule Zürich<br>Swiss Federal Institute of Technology Zurich | | Project: BLE and UWB Tag | |
| Drawing number: 1 | Rev: 1.0 | Format: A4 Q | Laboratory: Center for Project-Based Learning | Sheet: main.SchDoc |
| Date: 21.10.2021 15:20:20 | | | Drawn by: Silvano Cortesi | Page 1 of 4 |
| File: Y:\Documents\BLE_UWB_Board\schematics\main.SchDoc | | | | |

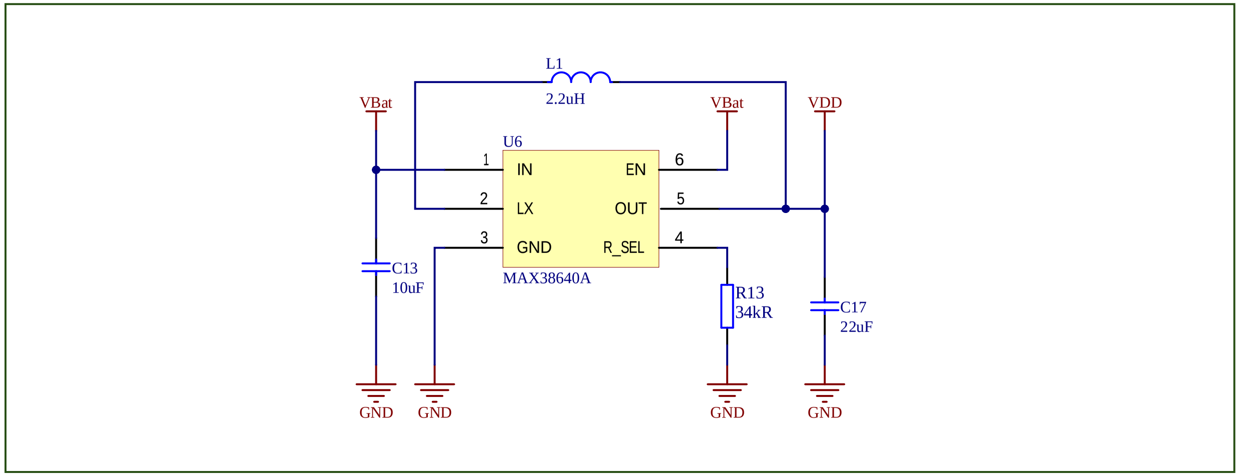
# USB Circuit




# LiPo Charger

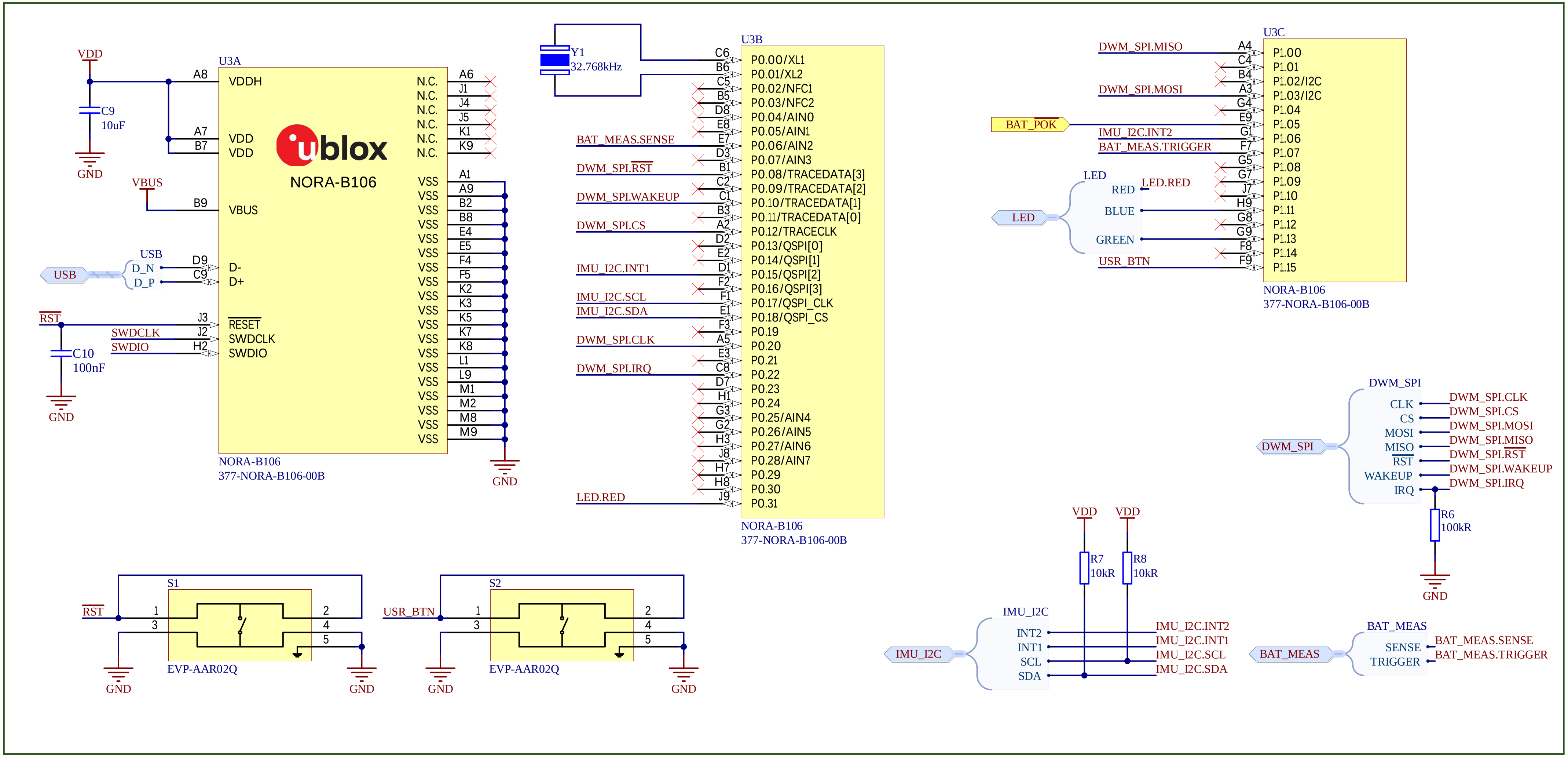



# 2.75V Buck Converter

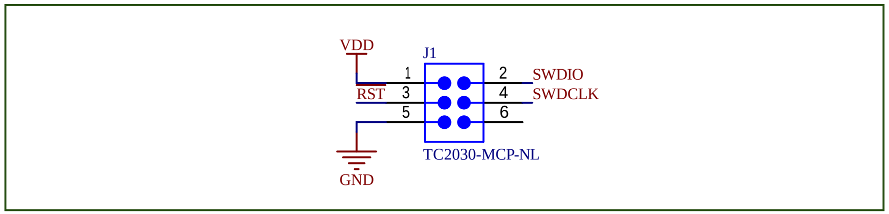



| | | | | |
|---|---|---|---|---|
| ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich | | Project: BLE and UWB Tag | | |
| Drawing number: 2 | Rev: 1.0 | Format: | Laboratory: Center for Project-Based Learning | Sheet: power.SchDoc |
| Date: 21.10.2021 | 15:20:20 | A4 Q | Drawn by: Silvano Cortesi | Page 2 of 4 |
| File: Y:\Documents\BLE_UWB_Board\schematics\power.SchDoc | | | | |

# MCU & BLE




# Programming Connector

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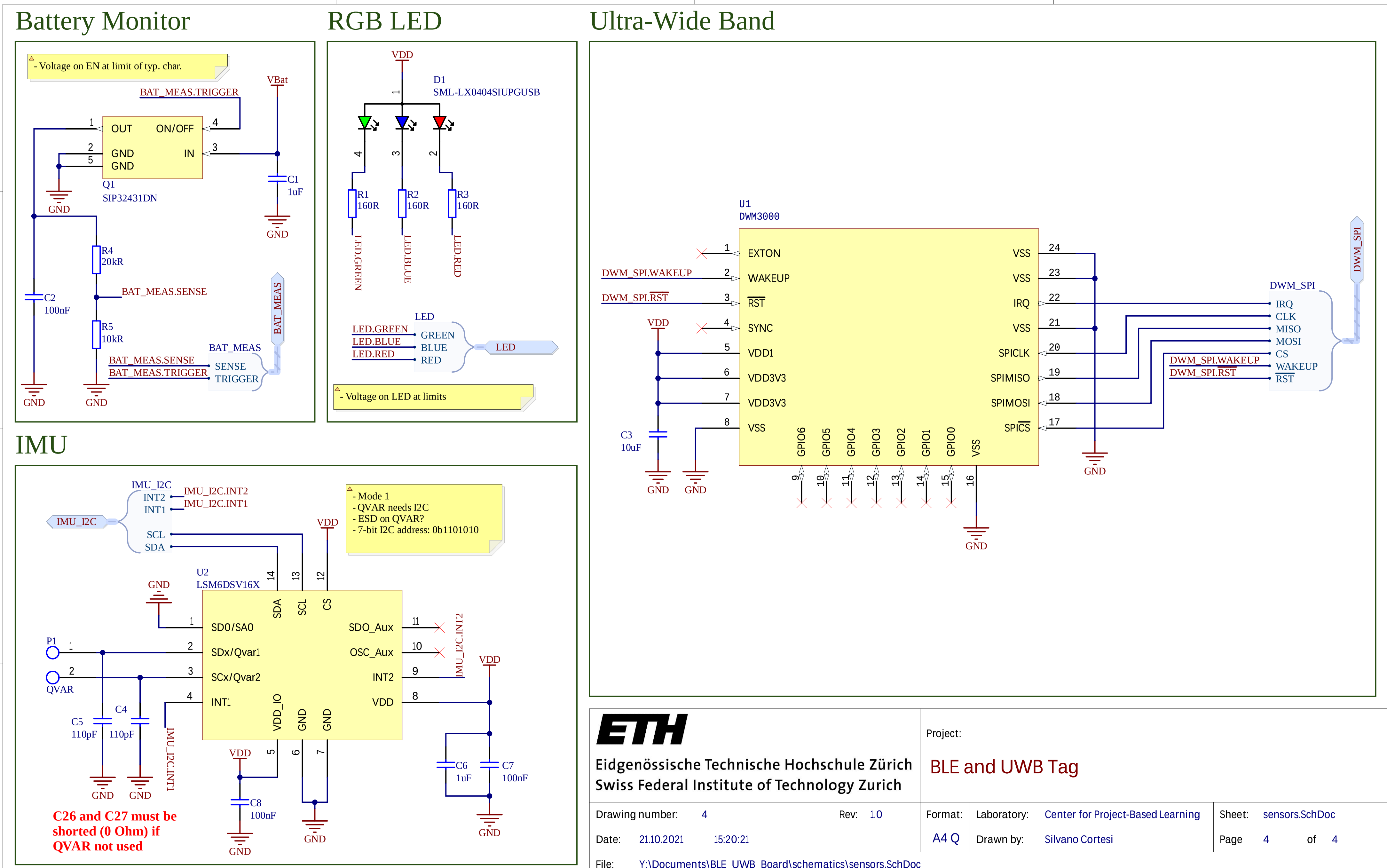
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

| | | | |
|---|---|---|---|
| Project: | BLE and UWB Tag | | |
| Drawing number: 3 | Rev: 1.0 | Format: | Laboratory: Center for Project-Based Learning | Sheet: mcu.SchDoc |
| Date: 21.10.2021 15:20:20 | | A4 Q | Drawn by: Silvano Cortesi | Page 3 of 4 |
| File: Y:\Documents\BLE_UWB_Board\schematics\mcu.SchDoc | | | | |




Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Project: BLE and UWB Tag

Drawing number: 4 Rev: 1.0
Date: 21.10.2021 15:20:21
Format: A4 Q
Laboratory: Center for Project-Based Learning
Drawn by: Silvano Cortesi
Sheet: sensors.SchDoc
Page 4 of 4
File: Y:\Documents\BLE_UWB_Board\schematics\sensors.SchDoc

Appendix E

# Zephyr Code Appendix

## E.1. Application

### CMakeList.txt

```
cmake_minimum_required(VERSION X.XX.X)
list(APPEND ZEPHYR_EXTRA_MODULES
  $ENV{PROJECT_ROOT}/modules/foobar
  )
list(APPEND BOARD_ROOT  $ENV{PROJECT_ROOT})
set(BOARD foo)
set(SHIELD egg_bar)

include($ENV{ZEPHYR_BASE}/cmake/app/boilerplate.cmake NO_POLICY_SCOPE)
project(app)
target_sources(app PRIVATE main.c)
target_include_directories(app PRIVATE .)
```

## E.2. Modules

### CMakeList.txt

```
zephyr_include_directories(
    driver
)
zephyr_library()
zephyr_library_sources(
```

```
    driver/driver.c
)
```

**module.yml**

```
name:
  foobar
build:
  cmake: zephyr
  kconfig: zephyr/Kconfig
  settings:
    dts_root: zephyr
```

**modules.cmake**

```
set(ZEPHYR_FOOBAR_CMAKE_DIR ${CMAKE_CURRENT_LIST_DIR}/foobar/zephyr)
set(ZEPHYR_FOOBAR_KCONFIG   ${CMAKE_CURRENT_LIST_DIR}/foobar/zephyr/Kconfig)
```

Check if this can be left out?

# Glossary

- .
- .
- .
- .
- .

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