Luleå University of Technology

Dept. of Computer Science, Electrical and Space Engineering

Master Thesis Engineering Physics and Electrical Engineering *VHF-Unit*

Läs igenom, engelska

August 16, 2018

Abstract

~~tracking~~ ?

ok

Surveillance and control have come a long way in the last years. Every new mobile phone, most cars, and smartwatches have a Global Positioning System (GPS) tracing device built into it. This is just one of the technologies used in ~~order to~~ track and follow. Today it is hard to go anywhere without there being some sort of way of finding you. The art of finding has been around for a long time and one company that have taken the tracking aspect to the next step is Followit. For over 40 years they have built different types of satellite and radio transmitters to keep track of everything from small animals like hares and dogs to big elephants. They also got tracking solutions for vehicles like boats, cars, trucks and excavators.
The purpose of this thesis is to develop a radio transmitter which can transmit on both the Very High Frequency (VHF) and Ultra High Frequency (UHF) frequency band. A first Printed Circuit Board (PCB) prototype board is made and from this, a final design is created. To ensure that the development process proceeds as planned in following steps, thorough testing is done both in hardware and in software.
The thesis includes a first PCB prototype and one final design which is ready to produce by the production team. Further programming is left for the developers at hand.
The results of this work is a four-layer PCB that is 25x15 mm in size and holds components on both sides. All but one component is tested and works as intended on the board. A first simple casing is done to enclose both the PCB and battery as a complete system. The system is programmed to run a simple code which tests the different systems and components. To test the wireless radio transmissions a small radio pulse is sent out which can be captured by a transceiver.

Varför behövde dem ett nytt kort ?

Preface

I would like to thank all the personal at Followit for taking me in and helping me through the project time. A special thanks to Bengt Evertsson for his help and all the good tips throughout the board layout development. Many thanks goes to Hans-Erik Persson who has invested much time and effort in my work and has been the main source of information regarding the software in the system.
A big thanks goes to my supervisor Jonny Johansson at Luleå Tekniska Universitet (LTU) for his support and guidance in the project.

Josef Lundberg
Lindesberg, August 16, 2018

Contents

Abbrevations

BGA Ball Grid Array (BGA) is a ?? package using small solder balls already connected to the component. 39

CAD Computer-aided design (CAD) is a computer system which aids the creation and modification of some kind of design. 31,

CLE CLass E (CLE, is a highly efficient switching amplifier type. 8

CPHA ClockPHAse (CPHA) determines the timing of the data bits relative to the clock pulses. 10

CPOL ClockPOLarity (CPOL) sets the property for the clock signal at Serial Peripheral Interface (SPI) 10

CTS Clear To Send (CTS) Is a command used by the radio chip to ensure that it is ready to recieve the next command 29

EMC Electromagnetic compatibility (EMC) is the ability of an equipment or system to function in its electromagnetic environment without causing unacceptable interference in this environment. 40

GPIO General Purpose Input Output (GPIO), is a general use port of an Microcontroller Unit (MCU). 18, 19, 29

GPS The Global Positioning System (GPS) is a radionavigation system owned by the United States government and operated by the United States Air Force. It uses sattelites for geolocation and time. i

HASL Hot Air Solder Leveling (HASL) is a process where the PCB's are dipped in to a bath of molten solder and then the excess solder is blown away by air knives 14

I^2C Inter-Integrated Circuit (I^2C), is a serial computer bus. vi, 4, 11, 16, 22, 37

IC Integrated Circuit (IC) is a set of electronic circuits on one small flat chip. 1, 8–10, 18

IMU Inertial Measurement Units (IMUs) are integrated circuits that can measure acceleration, rotational velocity and magnetic field strength. 13, 21

JST Japan Solderless Terminal (JST) are a company making different types of connectors commonly used on PCB's. 24

JTAG JTAG is an industry standard for verifying designs and testing printed circuit boards after manufacture. 26

LDO A low-dropout regulator is a DC linear voltage regulator that can regulate the output voltage even when the supply voltage is very close to the output voltage. 13, 36

LED A Light-Emitting Diode (LED), is a two-lead semiconductor light source. 28, 37

LTU Luleå Tekniska universitet (LTU) is the northern most university in Sweden where this thesis is accomplished at. ii, 31

MCU A Microcontroller Unit (MCU) is a single computer chip designed for embedded applications. v, 2, 10, 11, 13, 15–19, 21, 22, 24, 26–31, 36, 37, 39, 41

MSB Most Significant Bit (MSB) indicates the first bit in a bitstream. 10, 29

PC Personal Computer (PC) is a multi-purpose computer whose size, capabilities, and price make it feasible for individual use. 2, 30, 36

PCB A Printed Circuit Board (PCB) is the common acronym when referring to populated circuit boards. i, v–vii, 1, 2, 4–7, 14, 15, 24, 26, 31, 36, 39–41

PWB A Printed Wire Board (PWB) is the common acronym when referring to unpopulated circuit boards. 2, 4, 36

RF Radio Frequencies (RF) is a set of frequencies used for transmitting data wireless between different systems. iii, 7, 8, 13, 19, 29, 36, 37

RoHS Restriction of Hazardous Substances (RoHS) is a directive against use of hazardous materials in electronics 6

RTC A Real time clock is an IC that is used to mesure time even when the main device is off. 13, 21, 22, 37

SCL Serial CLock (SCL) is the clock signal used in Inter-Integrated Circuit (I^2C) communication 11, 22

SDA Serial DAta (SDA) is the bi-directional line used in I^2C communication 11, 22

SMD Surface Mount Devices (SMD) are electric components soldered directly on a PCB instead of using through-holes. 40

SPI Serial Peripheral Interface Bus (SPI), is a synchronous serial communication interface specification used for short distance communication, primarily in embedded systems. v, 4, 10, 16, 18, 21, 28, 29, 36, 37

ST STMicroelectronics (ST) is a French-Italian multinational electronics and semiconductor manufacturer. 21, 41

TCXO Temperature Controlled Crystal Oscillator is an precise type of clock source which compensates for temperature differances. 18, 37

TI Texas Instruments Inc. (TI) is an American technology company that designs and manufactures semiconductors and various integrated circuits. 23, 42

UART Universal Asynchronous Receiver-Transmitter (UART) is a computer hardware language for asynchronous serial communication. 5, 16, 30, 35–37

UHF Ultra High Frequency (uHF) is the frequency band spanning all the frequencies from 433 to 434Mhz. i, 13, 19, 20, 29

VHF Very High Frequency (VHF) is the frequency band spanning all the frequencies from 30 to 300Mhz. i, 13, 18, 19, 29, 31

VIA Vertical Interconnect Access (VIA) is a copper plated hole in the PCB for connecting a trace or plane between different layers. 8, 14, 35

WEEE Waste Electrical Electronic Equipment (WEEE) is an European directive for collecting, recycling and recovery of electrical and electronics waste. 6

XLP eXtreme Low-Power Features (XLP) is an low power mode for this particular type of processor 16

1

Introduction

This chapter describes the idea behind and the background to this project. A rough sketch of how the work is divided and the goals for this project is provided. Some ethical and usability aspects are also considered.

1.1 Background

Followit is a company that specializes in radio and satellite systems which are mainly used for tracking and surveillance purposes. Their office lays in Lindesberg. Followit has produced different types of radio sending units for over four decades now, this is not a new area of products for them. With new and improved technology arriving each and every year new products ought to be made to have the latest most efficient and effective systems. Every generation of a component will most likely have a smaller physical size, have more advanced features and draw less power than the previous one. Followit wants to make a new unit which implements all the new and improved technologies into a small, advanced product with low power consumption. Customers have been asking for a simple, small and cheap radio unit from the company to complement their more advanced and powerful products. With this type of product, they could produce them in a larger number and gain new sale territories. By having such a small product it can be used in new areas that they never could before. The smaller the animal you want to track, the smaller equipment you could strap to them. that should be used

?, ordered

now

Most of the Integrated Circuit (IC)'s are already chosen by the company, but there are no actual implementations. The final version is supposed to work in different areas, both as a tracker for animals and also as a product for theft protection in cars and vehicles. This means that the design of the product needs versatility to work in all these different areas. Much consideration is taken to get the product both small and inexpensive. The cost of the PCB depends on the size, manufacturing and the numbers of layers. The rest of the cost comes down to the components, batteries, and casing.

1.2 Project goals

för exjobb eller för företagets projekt ?

Followit wants to produce a radio sending unit which has a powerful MCU for advanced programs and with some extra features that make it possible to use the finished product in different areas and with different types of characteristics. The project involves a first test prototype and a final version which is presented to the company as a finalized product ready for marketing and sales. To ensure proper functionality of the prototype a test program is written to the system to test the connection and functionality of all the components and accessories. Connected to a Personal Computer (PC) interesting data from each and every component is displayed clearly in a console window. The radio signals are sent out and with a separate receiver for each of the frequency bands, they are both presented as a clear audible note.
Both the cost of the bare board and the components need to be kept down. This requires some special attention to the board design, the manufacturing and component selection. The goal is to make the product both small and cheap at the same time. The formulation will be considering making a prototype which is tiny but has a high manufacturing cost and an inexpensive that have a bigger physical size. The procedure will be to find a good balance between the two.

ordval ? (balance ?)

ordval ? (challenge ?)

1.3 Scope

The main focus of this thesis is to create a PCB prototype that is tested and well designed and works as intended. Some of the components in the product are predefined but their implementation has to be done. Extended test code is written to the product which includes tests for all the components in the circuit. Two PCB's will be produced, the first one is ordered just as a Printed Wire Board (PWB) and all the components are hand soldered at the company. The second PCB will be produced and assembled from a manufacturer in China. The final PCB design will be delivered to the company for further programming and implementation. In the case of time, a casing for the product as well as battery considerations will be made.

1.4 Approach

The idea that was presented at the start of this project was a half-finished principle that I needed to understand and also expand with all the necessary components that are not mentioned in this design. The initial work prior to this project can be seen in Figure 1.1.

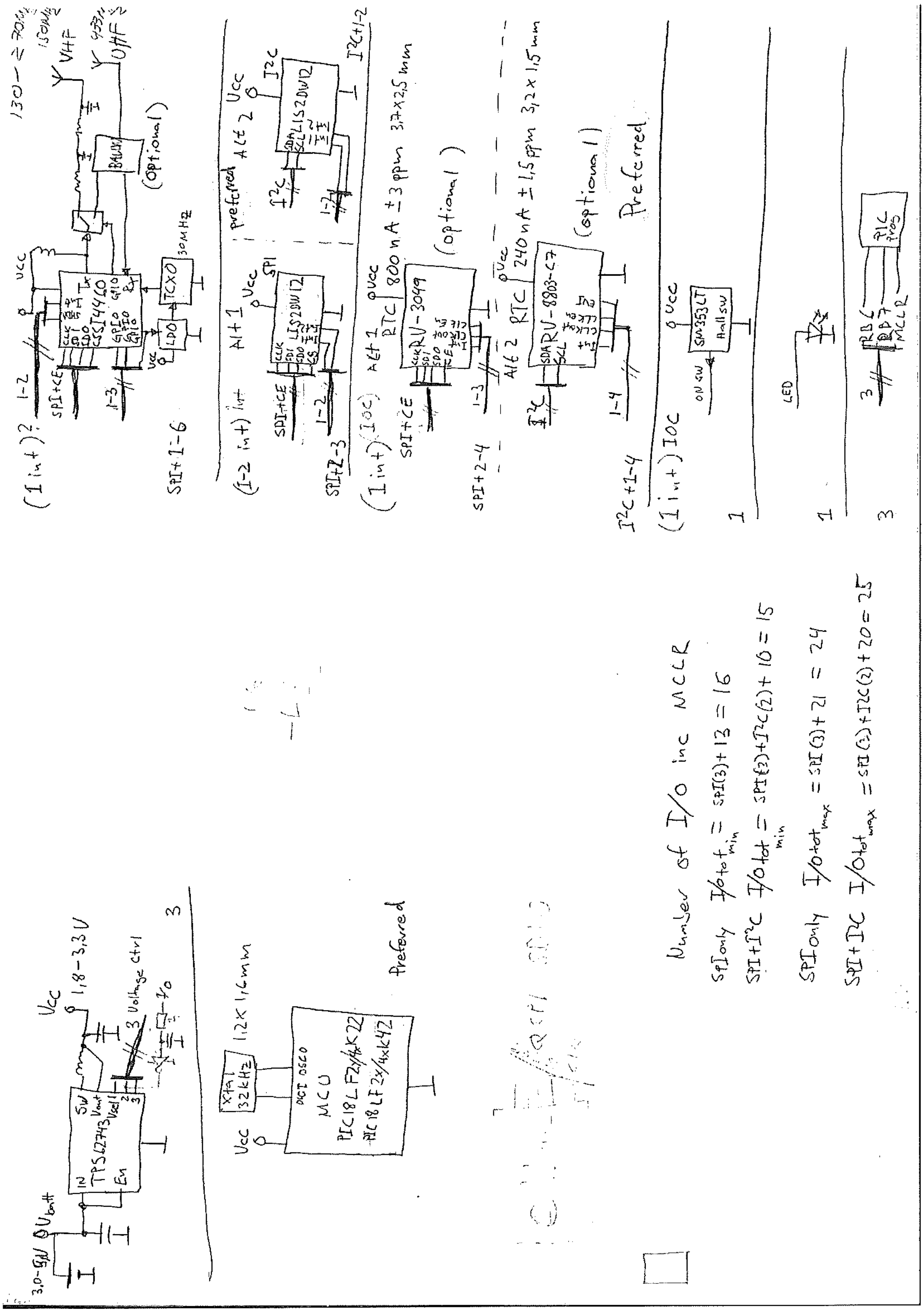


Figure 1.1: The initial schematics made by Followit
Source: Author

To get to the point of making the actual PCB a thorough analysis of the components and their connections need to be made. Firstly the data-sheets are considered for an understanding of the component itself and the required connections for this particular implementation. Both power and data are crucial for operation and there might also be some peripherals connections and chip selection that need to be considered.
When a complete schematic for the system is completed a layout for the PCB is created. The layout comes is two separate designs. The first one is a prototype board which is ordered just as a bare PWB. To this, all the components are ordered and then soldered by hand at the company with the help of an infrared PCB preheater, hot air heat gun and a small tipped soldering iron. The second layout is supposed to represent the final version. This is ordered assembled directly from the same board manufacturer.
By writing a program the functions of each individual component can be tested. The processor used in this project comes from the PIC18 family of 8-bit processors produced by Microchip Technologies. This processor is a fairly simple unit, which makes it a bit more challenging to program. It doesn't have a bunch of advanced libraries for example communication through SPI or I^2C like some other commonly used processors. The process will, therefore, involve some close to hardware programming. A more thorough description of the processor will be given later in this report. The code language used for this project is C.

1.5 Ethical and usability aspects in

ordval

When designing a system meant for tracking and surveillance, one can think of the aspects of this. Tracking animals can be used by both the agricultural and animal rising as well as studies of wild animals. The radio unit can also be attached to vehicles or equipment. One aspect of a radio tracking device is that no special equipment or extra security is considered. If someone wants to track the radio unit one can do so without a problem, there is only the matter of finding the sending frequency and start searching. The unit is constructed for easy usability, with almost no ways to interact with the product. Without buttons, interface or cables it is set up initially at the company to match all the customer's criteria, scheme, and functions directly out of the box. The system can, however, be accessed through the Universal Asynchronous Receiver-Transmitter (UART) interface on the PCB. When sold the system is enclosed and will therefore not be able to communicate this way. The only way of transferring data to the unit is with the use of the radio. This is to possibly change the scheme, function, and settings. This function is implemented in the hardware but possibly not used for this product until later in its life-cycle when the function is considered to be useful.

Kanske gör att fram nåt här om att en etisk
aspekt är om obehöriga trackar någon,
Det är nog det du skriver, men det är
(för mig) lite otydligt.

2

Theory

This chapter will introduce the reader to the underlying technologies taken into account. The principle of radio communication and the important steps involved in developing a new product prototype will be presented. Basic information about the communication and programming will also be presented.

2.1 PCB

Bra! Velbeskrevet!

Good electrical characteristics are of most importance for this system. This is achieved by making the system on a four-layer PCB. This has a lot of advantages over a standard two-layer board. The four-layer design will have a top layer which holds some of the components, a bottom layer with extra room for tracing tracks, components and having an additional ground polygon. The two inner layers consist of a power-plane and a ground-layer. Benefits of this are both easier to draw traces and also as a good way of making the circuit more resistant to high-frequency noise between the traces on the top and bottom layer. The laminate material used in the PCB is standard FR-4, glass fibre, and epoxy resin. This material has low water absorption, is fire resistant and have good mechanical characteristics. All the components and soldering tin are free from lead, mercury and other hazardous materials following the Restriction of Hazardous Substances (RoHS)-directive. ref. The components for the final prototype is ordered in a small number as the final product is produced elsewhere and has to source the components directly. The finalized prototypes that are not used or is faulty will most likely not be fixed in any way and will, therefore, be recycled. Following the Waste Electrical & Electrical Equipment (WEEE) standard these products will be recycled and taken care ref. of in their end of life. The wheelie bin symbol of WEEE is added to each circuit board to warrant this.

2.1.1 Design rules

Some design rules are presented which will help the layout process and make the circuit have the best chance of success. These are some guidelines which should always be followed when designing a PCB.

Skum mening

uppräkn.

- Trying to have the ground-plane as intact as possible making it span as much as possible on the outermost planes.
- Components are moved around to get the ground-plane as big and intact as possible.
- Deleting smaller ground planes to and drawing traces in a smart manner to eliminate these smaller ground polygons.
- Always avoiding making 90 degree bends on the signal traces to avoid deflection of the signal.
- Keeping the ground plane intact on the entire plane, not splitting up in any way. This implies on the power-plane as well.

2.2 Radio Frequenc~~y Design~~ies

Radio frequencies are a set of frequencies that are used for transmitting and receiving data wirelessly. Radio frequencies begin at one end of the spectrum where the frequencies are about 100Hz. It contains all the frequencies up to 300GHz. Radio frequencies are divided into different bands, all with different characteristics and areas of implementation. A frequency spectrum is provided in Figure 2.1.

Detta stycke känns lite tunnt. Kanske gör att skriva någon mening om att det är EM vågor etc. Input längst. (+ ref)

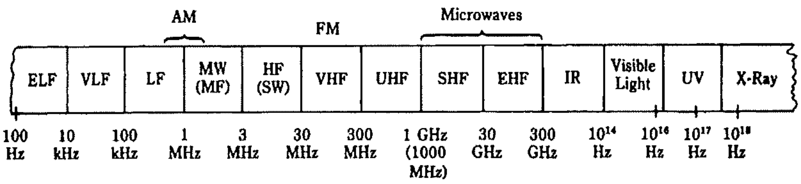


Figure 2.1: Electromagnetic frequencies
Source: RF Circuit Design [19]

2.3 Design challenges

Designing a circuit for radio transmission is an advanced and complex procedure. The high frequencies introduce a lot of interesting phenomena that need to be considered when constructing a circuit in these frequencies. When designing a circuit for RF, components and traces on the PCB behave~~s~~ in a different way and take~~s~~ on different characteristics than an equal system at lower frequencies. Some aspects that need to be considered in the layout is described below

- Make the traces that holds RF frequencies be the equivalent of 50Ω between all components and circuitry.
- The traces should have rounded bends.
- Make the traces as short as possible.

skulle behöva förklaras

The amount is same, but its effect is higher for higher frequencies

- Have a ground plane with Vertical Interconnect Access (VIA)s around the traces to ensure no cross-talk to the rest of the system.
- A generous amount of VIAs in the ground plane and on the sides of the board to further ensure good characteristics.
- The ground layer should not be broken under a high-frequency trace.

Some of the challenges that arise are described in Secrets of RF Circuit Design [17]. Stray capacitance is one phenomenon that arise when handling RF. Between conductors, conductors to ground and between components a small capacitance occurs when dealing with RF. This is negligibly small in lower frequencies but now in the higher RF frequencies this can be a considerable amount.
Another phenomenon ~~that introduces~~ is the so-called skin effect, where the "skin" part comes from the physical phenomena that are happening. When the frequencies rise the resistance in a conductors core increases with it. As current choose s the path of least resistance ~~and~~ it will therefore in higher frequencies flow only on the outside most part of a component. A visual explanation of this can be seen in Figure 2.2.

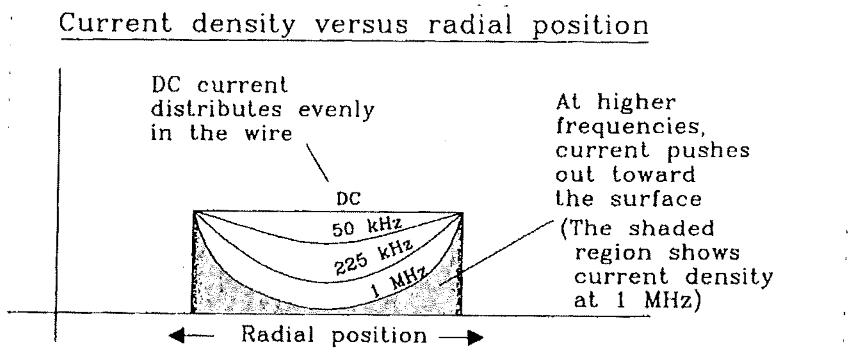


Figure 2.2: Skin effect in components in RF
Source: High Speed Digital Design[18]

The output signal from the radio transceiver is matched at 50 ohms and this has to be matched with the output stage components. These components commonly is a network of inductors and capacitors. This matching network is described later in this section. From different types of radio signal transceiver, the type used in this case is determined by the radio IC's manufacturer. [9]

2.3.1 Class E amplifier

The CLass E (CLE) amplifier type used here uses switching type of amplification to increase efficiency and reduce power loss. The most interesting part of CLE is the fact that up to ideal power efficiency can be achieved by constructing this type.
[20]

Vad är detta för filter? Beskriv.

2.3.2 Radio antenna filter

Stating in the datasheet to the radio IC the rough design aspects are defined. The Chebyshev filter is recommended for this radio for its good characteristics in the stop band as well as having relatively good characteristics in the pass-band.

skum mening

~~2.3.3 Chebyshev Filter~~

Behövs ej egen rubrik

The Chebyshev type of filter is special in the fact that it has a steep fall rate with the disadvantage of having a bit more ripple at the pass-band. These filters are mathematically derived from the Chebychev polynomials. This makes it very suited for radio designs were the steeper fall rate helps with eliminating higher frequency noise. The higher the order of filter makes for a steeper fall rate, but it also makes for a physically larger filter.

ref

2.4 SPI

SPI communication is used to communicate between the MCU and other IC's on a circuit board. SPI uses four wires to communicate and an additional one wire for each extra IC that is connected. The transmission works in a synchronous serial manner where each bit is sent one at the time synchronous to a supplied clock signal. Different types of SPI connections exist but with the most common being the four-wire serial bus. Here SCL, SDO, SDI, and SS ~~is~~ are used [2].

- SCL - Serial CLock, a clock is supplied to synchronize the data transmissions.
- SDO - Serial Data Out, Data is sent from this port.
- SDI - Serial Data In, Data is transmitted to this port.
- SS - Slave Select, Selects a device for communication.

Eight bits are sent together to form a package of one byte. In these eight bits the function and type of each transmission are defined, either by setting the Most Significant Bit (MSB) or some other type of set parameter for each component. Four different modes are available when communicating through SPI. These modes determine which type of clock signal provided and how the data is sampled in the devices. Two different types of clock-signal, one where the clock is pulled high when idle and the other one pulled low when idle. This is often called in the registers as; ClockPOLarity (CPOL). The other mode selects the timing of data bits relative to the clock signal. Data is sampled either when the clock signal goes high or in the middle of a clock pulse. Clock-Polarity (CPHA) is the often the name of this selection. This concludes the different modes. A visual explanation of SPI communication is provided in Figure 2.3.

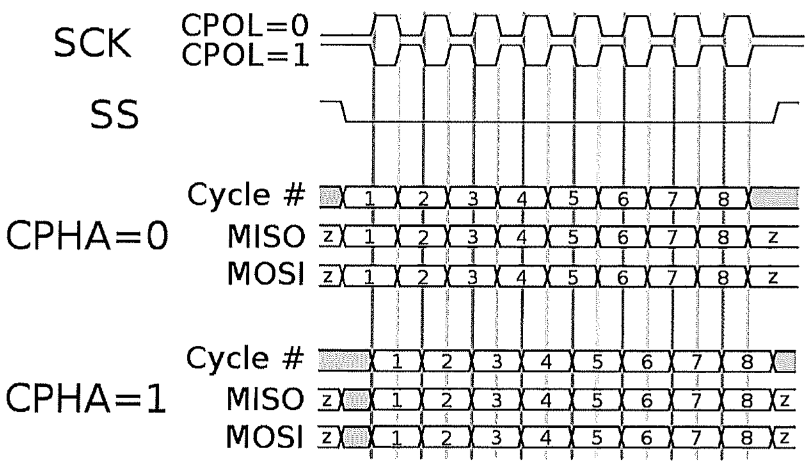


Figure 2.3: Timing and modes for a transmission over SPI
Source:
`https://commons.wikimedia.org/wiki/File:SPI_timing_diagram.svg`

The interface uses one master device and multiple slaves. The master device handles the communication and supplies the selection of slaves. To enable a connection and choose which slave is used an individual slave select must be present. When set, only the chosen slave device is able to communicate. From the MCU's datasheet the following diagram show in Figure 2.4 how the connection works when connection several slave devices.

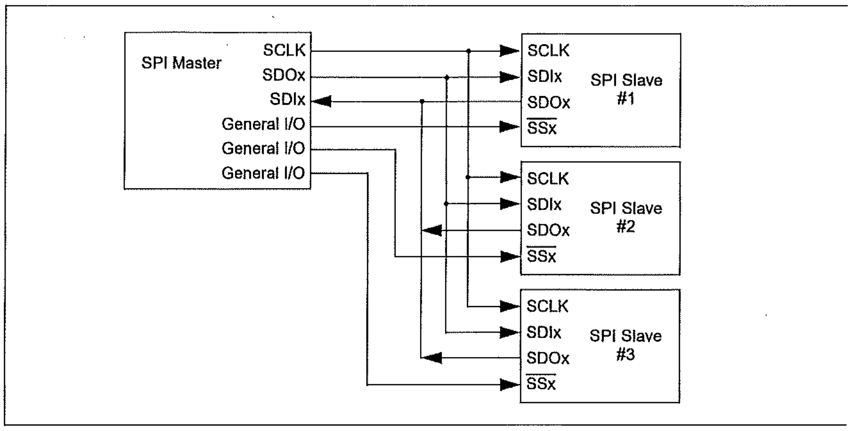


Figure 2.4: SPI master and multiple slave connections
Source:
`http://ww1.microchip.com/downloads/en/DeviceDoc/40001412G.pdf`

Data is sent out from the MCU at the SDO wire and at the other end connected to the SDI pin of a receiving device.

2.5 I^{2}C

A more advanced type of communication is I^{2}C. I^{2}C is more often used in larger circuits or when the distances are longer. Only two lines is used in I^{2}C communication, Serial DAta (SDA) and Serial CLock (SCL). SDA is used bi-directional to both send and receive data. Bidirectional communication is achieved by an "Acknowledgement" system. This "Acknowledgement" system works by sending one bit "ACK" back whenever the other part has received and got the right type of data. It allows for both the slave and the master to send and receive data on the same line. The SCL line only sends out the clock signal to synchronize the data signal. The I^{2}C interface uses pull-up resistors to set the idle state of the signals high. Different communication speeds require different types of resistors, with the higher resistors not able to handle faster transfer speeds but draw less power when transmitting data. The structure for reading and writing have a similar structure. A typical read scenario starts with a start bit followed by the control in bytes. The slave device then sends back an "ACK" to ensure that it could read the command correctly [3]

3

Hardware

From the objects described briefly in earlier chapters, a complete system is constructed. A deeper look into each component with some information of their functionality and implementation will be presented in this chapter. Why some specific components are chosen is also answered here.

3.1 Structure

The product is constructed with a number of components, which all have a central role in the final product. Each of the components of this project is carefully chosen to get the functionality and effect that the company is after. As described earlier the company's idea is considered and expanded to a complete system. The components are considered and studied to understand their function and position in the system. To the system, some essential components are added to get the functionality the company is after. A list is constructed for the different main components covering their role and function in the system. This can be seen below:

- **MCU:** The central part of an integrated system, handles all the calculations and the program code. Connecting all peripherals together to a complete system.
- **Radio:** All the communications with the rest of the world will be handled by the radio, sending on the VHF and UHF band.
- **RF switch:** It switches the signal from the radio between the UHF and VHF low-pass filters.
- **Inertial Measurement Unit (IMU):** Movement detection is measured with an accelerometer, this to determine if the unit is in motion or lying still.
- **Low-dropout regulator (LDO):** A Low-dropout regulator can supply the system with a voltage level very close to the input voltage due to no diode voltage drop inside the component.
- **Real time clock (RTC):** A real-time clock is important to acquire data at a specific set time. It is important that the clock is exact over the whole life of the product.
- **Hall sensor:** The hall sensor is used as a switch for the system by sensing if a magnet is nearby and then turning off the circuit. This implementation is already used by the company.
- **Programmable buck converter:** To alternate the supply voltage for the system.
- **Miscellaneous components:** Two Light-emitting diode (LED)'s, two oscillators, one for the processor and one for the radio module.

A visual description of the main components and their respectively connection is compiled and can all be seen in Figure 3.1.

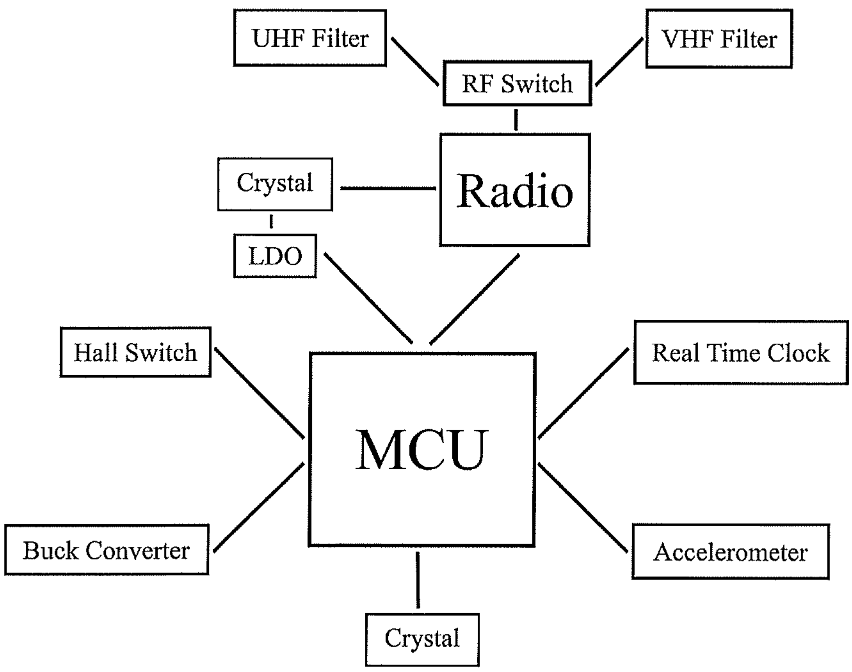


Figure 3.1: The prototype connection
Source: Aurthor

Stan.

3.2 Layout parameters

When starting the layout some initial rules need to be set up. These parameters are set by the board manufacturer. The design can be produced at different places but when ordering from this manufacturer the constraints that are used is the same parameters that the supplier uses as their standard. The board assembly manufacturer used is called ALLPCB.[7] These rules and constraints may differ from one supplier to another but as the company already uses this supplier the same will be used for this project. Naturally, for this project, the minimum spaces and distances that does not make for a supplement charge are chosen as the design rules. A list of these parameters can be seen below. These are the parameters that defines the circuit boards made.

- Trace width: minimum of 6 mils (0,1524mm)
- VIA diameter: 0.3 mm
- Thickness of board: 1.6 mm
- Copper thickness on all layers: 1oz enhet ?
- Surface finish: Hot Air Solder Leveling (HASL), lead free

3.2.1 Landgrid

In order to mount the components on the PCB the correct pads or landgrids as they are called are needed. Each component on a PCB have their own landgrid design, which corresponds to the components contact pads. These pads are copper pads on the PCB which is left open and separated from the solder resist material covering the rest of the PCB to hold the component and the solder. Often are the pads a bit larger than the actual contact point of the component to accommodate some additional solder and making the soldering process as easy and trouble-free as possible. To ensure the pads are optimal and give the best production capabilities the industry standard is aimed for. For all the passive components and the most ~~common~~ component packages, the designs are taken from IPC's design guideline[?]. One simple land-grid design used in this report is the 0402 package ~~size for~~ passive components, the design can be seen in Figure 3.2.

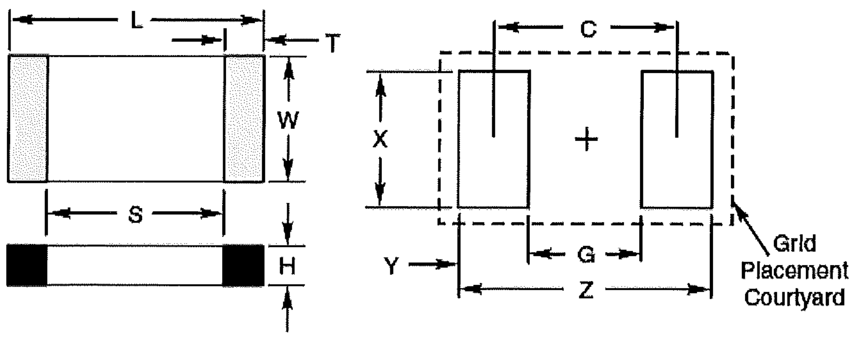


Figure 3.2: Landgrid for passive components, 0402 package
Source: IPC-standard

While these are made for optimal manufacturability the footprints used on the first test board they are modified to enable for easier solderability and rework if needed. The landgrids are made slightly bigger and longer to achieve this. The downside of making the pads larger is that each component takes up more real estate and the final board size increases. The rest of the landgrids are made separately from scratch using the dimensions specified in the data sheets.

3.2.2 Easy prototyping

The components that are going to be used in high frequency often come in tiny packages. The best components used in this area of work will be small to fit in small modern advanced systems like mobile phones and other portable devices. This makes it harder to build a prototype which should be easy to solder and use. To make a prototype which is easy to troubleshoot and rework space is needed between the different components on the PCB. To most of the modules, a 0Ω resistor is used to easily connect one part of the system at the time in a troubleshooting scenario. This is also a good way of determining the individual power consumption of each module.

3.3 Micro Controller Unit

ordval

Every advanced system needs a central processing unit to make all the calculations needed. Why ~~a lot~~ of systems needs some powerful processor this system which is a bit easier can easily be run on a simpler unit.
The MCU used for this project is a processor type that is used by this company many times before and has been chosen to this project for its small size, low power draw, sufficient connections, and features. The particular processor used is the PIC18LF46K22[8]. This particular model is an 8-bit version. The version used is one with 40 pins. All the connections available are shown in Figure 3.3.

mellanslag

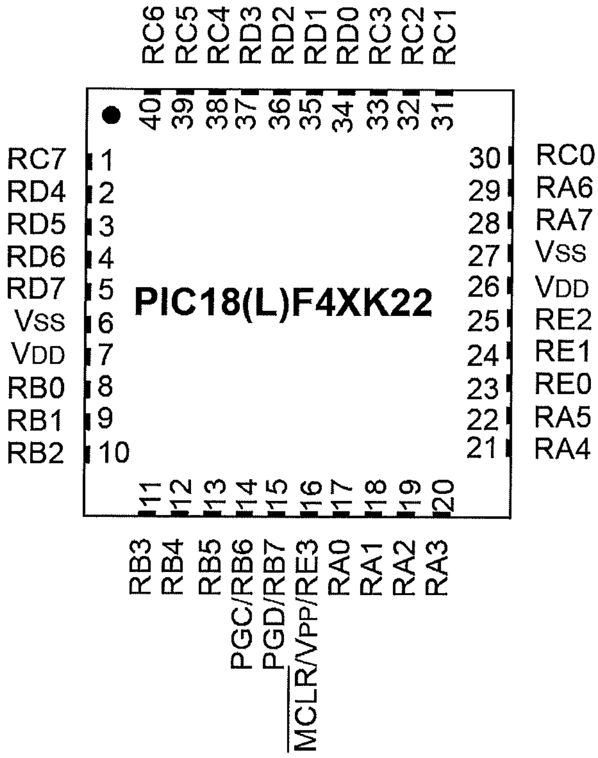


Figure 3.3: PIC18LF46K22 pinout
Source:
`http://ww1.microchip.com/downloads/en/DeviceDoc/40001412G.pdf`

Some of the features of this MCU are:

- 64kbytes linear program memory
- 1024 bytes EEPROM memory
- UART, I^2C and SPI communication
- In circuit programming and debugging
- Extended instruction set
- eXtreme Low-Power Features (XLP) with a 20nA sleep mode

3.3.1 Power

The component is a low-power model which can handle a lower source voltage. A voltage between 1.7 to 3.6 is required, anything lower will not start the device and anything higher will damage the part. Powering it is done by connecting the VDD pins to the power net. Connected to the ground is the Vss pins on the processor. To ensure the current fed is as smooth as possible capacitors are connected between these two pins. The value of these capacitors is chosen to 100nF.

3.3.2 Oscillator

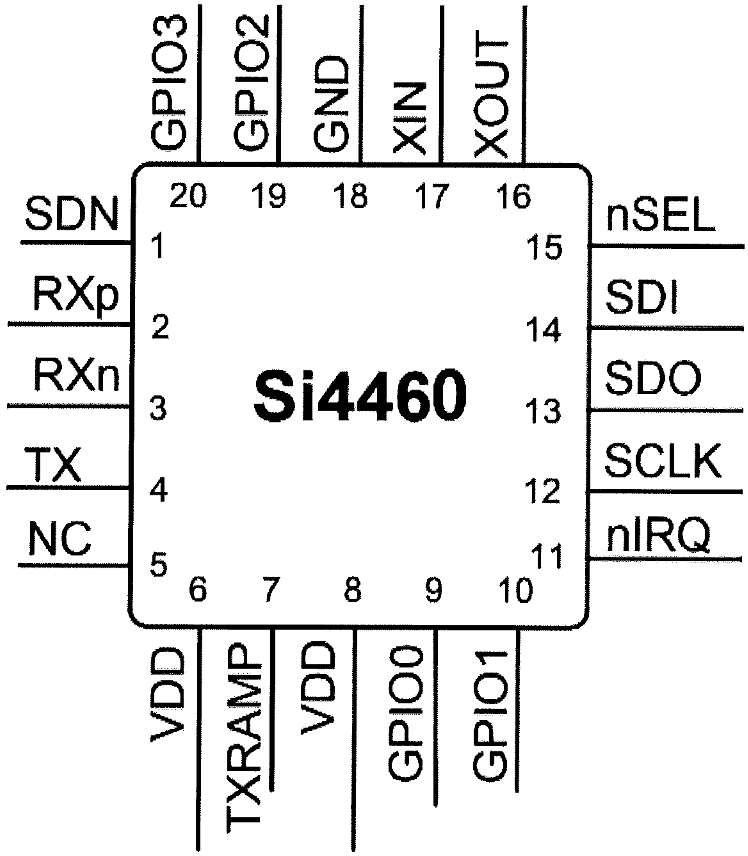
clock relies

To operate the MCU a clock signal is mandatory, this can be implemented in different ways. Either with the internal High, Medium and Low-frequency oscillator or an external one. ~~Where~~ The external ~~rely~~ on a specific circuitry to provide the clock source. Examples of external oscillators are clock modules, quartz crystal resonators or ceramic resonators and resistor-capacitor circuits. When a circuit is specified to be power efficient the speed of the clock plays a central role. As this product is specified to run on a small battery the speed of the system is kept low to increase the lifetime of the battery. The clock signal is generated from an internal oscillator.

3.4 Radio component

output amplifier

The radio module used in this project is from the company Silabs. The chosen radio IC have the characteristics that are wanted in this type of product. The radio ~~transmission~~ used is the earlier explained class E. With this piece the class E is already implemented in the radio as this is widely used today and a very power effective radio ~~signal~~. The type of filter used for sending radio signals at VHF frequencies is defined earlier in this report. The output power of the radio can be set to a maximum of 13dBm, but with the additional power consumption as a downside. A figure of the component is shown I Figure 3.4.



mindre stærk

Figure 3.4: Si4460 pinout
Source: `https://www.silabs.com/documents/public/data-sheets/Si4464-63-61-60.pdf`

Stavn,

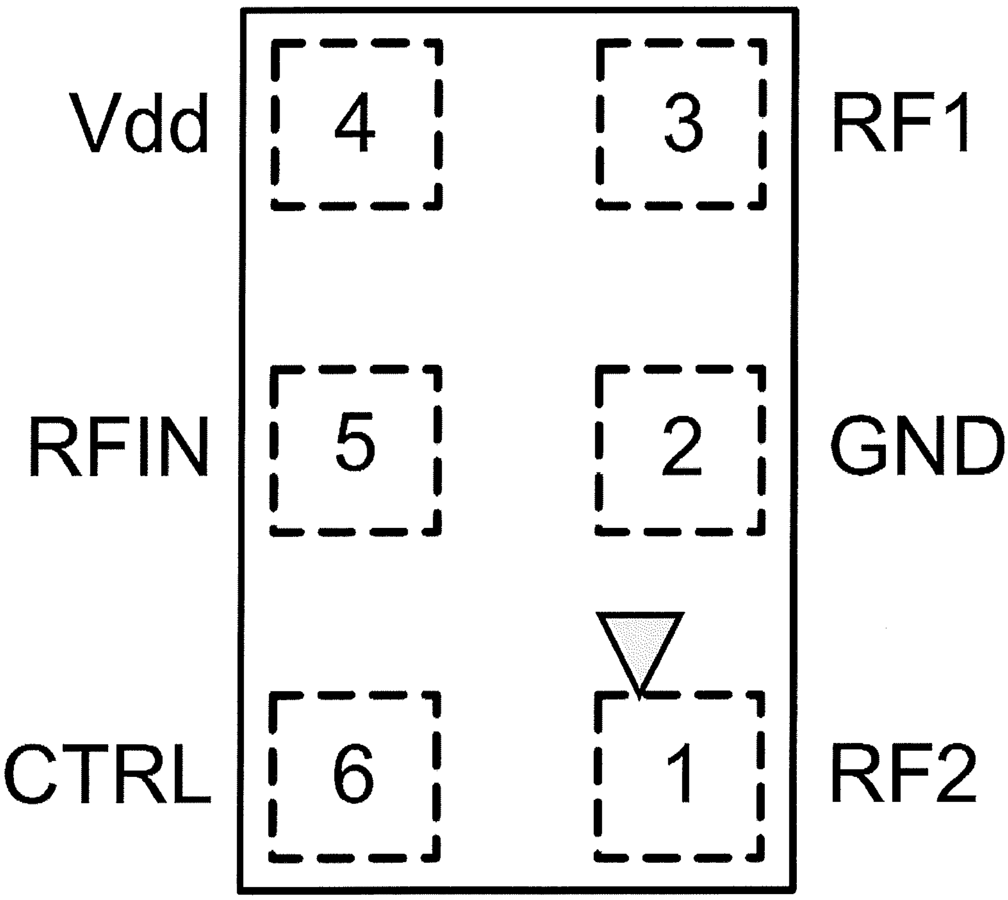
3.4.1 Connections

as decoupling

To power the radio a specific series of capacitors are used to minimize noise and spikes in the power plane. The four General Purpose Input Output (GPIO) can be independently programmable on the unit, two of which powers and controls the radio switch. To ensure a precise radio frequency independent of great temperature differences a Temperature Controlled Crystal Oscillator (TCXO) is used as the source for the clock signal. The oscillator only needs one connection, the XIN. Communication is done via SPI, this requires the four pins associated with SPI connected to the MCU. Transmission is done through TX and receiving and through the RX pair. SDN is used to turn off and reset the radio and this is also connected to the MCU.

3.5 RF-switch

To switch between sending the radio signal to the filter design for the VHF or UHF a particular switch is used. This component can handle the high frequencies and then send the signal to each of the filters. It is also matched at 50Ω to not interfere with the signal in any way. The component is called BGS12PL6 and manufactured by Infineon.



minsta storlek

Figure 3.5: Infineon BGS12PL6 pinout
Source: `https://www.infineon.com/dgdl/Infineon-BGS12PL6-DS-v02_04-en.pdf?fileId=db3a30433f1b26e8013f2db8ea4c385f`

3.5.1 Connections

The component is powered by the use of one GPIO pin from the radio. The structure is simple and easy to understand. The radio signal from the radio is taken in at "RFIN" and by setting the "CTRL" pin the output signal is switched between "RF1" and "RF2". Which then is connected to the two antenna filters.

a VHF filter

3.5.2 Antenna filter

Two different types of filters are used in the design. One filter is for the UHF band, for frequencies between 433MHz and 434Mhz. To this band, a simple filter using uses a balun, a complete compact low-pass filer all in one simple component. The other filter is constructed using passive components. This filter is constructed as described in an earlier section with a series of capacitors and coils. The capacitors are of the wire-wound type, this ensures that the filter has high Q value. The capacitors used are of the C0G type which is made of specific temperature controlled substrates which give them defined temperature dependent capacity. This type has a very low-temperature dependency which is important for this implementation. On the first prototype board, two filters are implemented. One is used to test the filter recommended by the manufacturer for using a frequency of 169MHz. The other filter is intended to be compared with the one specified by the manufacturer. This filter is a seven order Chebychev low-pass, which is calculated to have a cutoff frequency at 230Mhz. The values for each passive component is determined via this online calculator [5]. A visual representation of the frequency response for this can be seen in Figure 3.6.

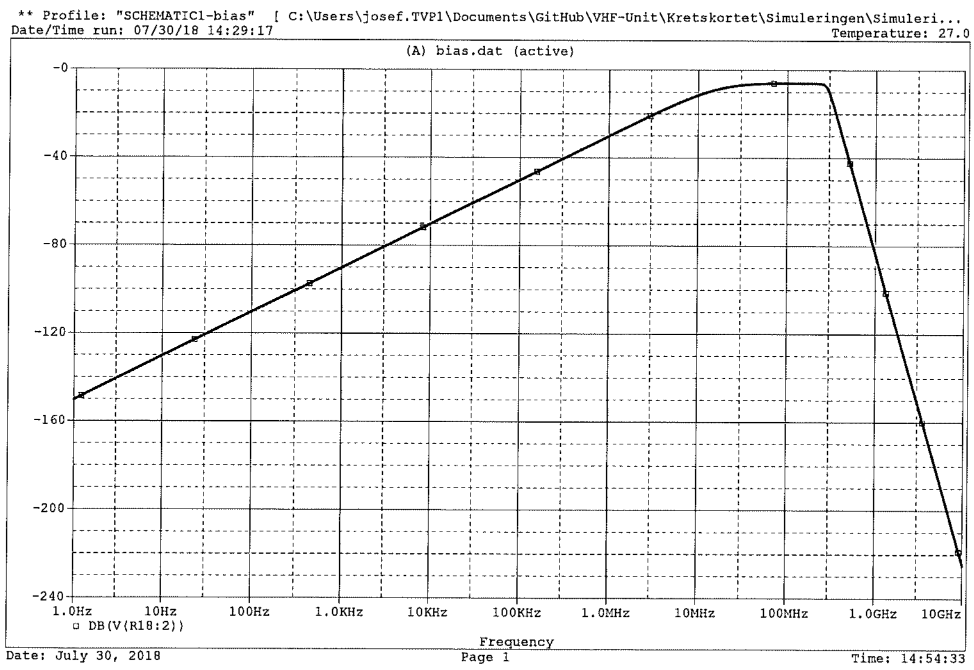


Figure 3.6: Frequency response for a seven order Chebychev filter
Source: Author

3.6 Accelerometer

The motions of the system are measured with a IMU system. This system can be used in a lot of different cases, both to detect if the unit is stationary or moving or if there are very hard and fast movements in the product. One of the simplest IMU's is the 3-axis accelerometer, it detects accelerations in three axes, x, y, and z. The component used is a 3-axis, ultra-low-power and high-performance accelerometer from STMicroelectronics (ST) [10]. The component which is called LIS2DW12 is the simplest of IMU's that this manufacturer has and this simplicity makes for a product that only incorporates one single function.

3.6.1 Connections

Two voltage connections are apparent on this device, one which is called VDD and the other is called VDD_IO. The VDD is the supply voltage and VDD_IO determines the logic voltage level. Both of these is connected to the power supply with two smoothing capacitors. One of the interrupt lines is used. Data is sent via SPI and this requires four connections. SCL, SDO, SDI and chip select. The RES line is connected to ground as seen in Figure 3.7.

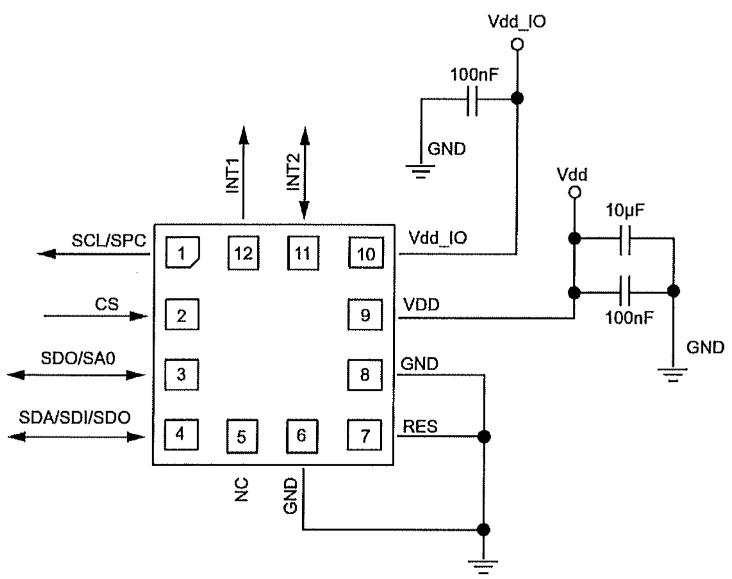


Figure 3.7: LIS2DW12 accelerometer pinout
Source: `https://www.st.com/resource/en/datasheet/lis2dw12.pdf`

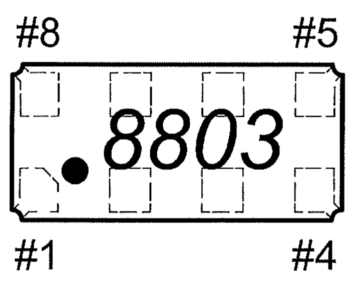
3.7 Real Time Clock

Exact time cannot be kept with only the MCU, the internal oscillator used is not tuned right to keep a persisting and accurate clock signal to measure time with high precision. A RTC is a great way of keeping time in an embedded system. This little device has a fine-tuned tuning fork which oscillates in a predictable manner. This coupled with an exact temperature compensation makes this component holds the exact timing for a long period of time.

In some cases.

When setting up this device it does not only holds the clock and calendar but also supports the features timer, alarm, and a temperature sensor. The RTC will keep the exact time with a maximum time difference of 90 seconds over the period of one year. This is however not important in all applications, as the embedded oscillator in the processor will be sufficient for keeping the time. The component is the only in this system that communicates via the I^{2}C protocol. The product used is manufactured by Micro Crystal and is called RV-8803-C7 [13].

RV-C7 Package: (top view)



#1	SDA
#2	CLKOUT
#3	V_{DD}
#4	CLKOE
#5	V_{SS}
#6	$\overline{INT}$
#7	EVI
#8	SCL

Figure 3.8: Micro Crystal RV-8803-C7 pinout
Source: `http://www.microcrystal.com/images/_Product-Documentation/02_Oscillator_&_RTC_Modules/02_Application_Manual/RV-8803-C7_App-Manual.pdf`

3.7.1 Connections

The component needs power and ground as well as the I^{2}C connections to operate. This connection is not high speed demanding and can, therefore, use pull-up resistors with high resistance. $10k\Omega$ is used, both on the SDA and SCL line. The interrupt line is an open drain and needs one pull-up resistor as well. The other connections are not of any use right now and are left unconnected.

3.8 Hall switch

The system needs a power switch to have the ability to have the system powered down when stored or waiting to be sold. Whit the use of a hall switch the product can be kept at an off state even when the device is complete and is totally encapsulated in the case. The function is that when a magnetic field is apparent the switch sends out a digital signal to the MCU which then can be used to put the system in a "sleep" mode.

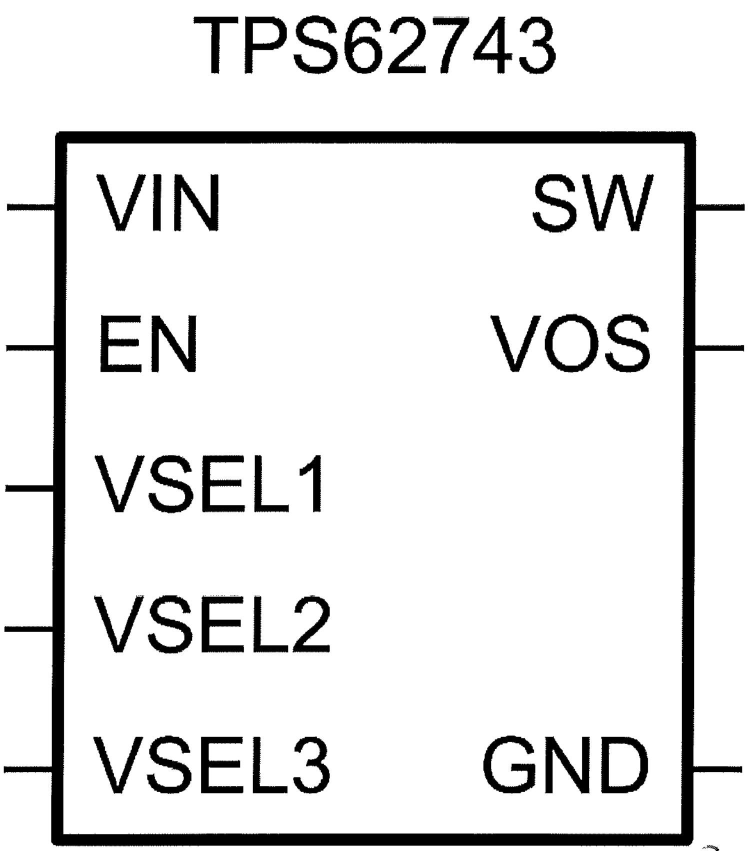
3.8.1 Connections

The device is powered from the power supply and will send the output signal at another lead.

3.9 Buck converter

The system is driven by a battery, but the voltage can be too high for the system and also goes down as the battery loses its charge. To get a stable and consistent voltage supply to the system a buck converter is used in between the battery and the rest of the system. It is manufactured by Texas Instruments Inc. (TI) and the name for it is TPS62743. This particular unit has the added benefit of having a programmable voltage level output. By setting the three selection lines any voltage between 1.2 and 3.3 can be chosen as the supply voltage to the system. Benefits of this are that in the middle of a program the supply voltage can be lowered for a simpler task which makes the system draw less power. The supply voltage can then easily be increased when a high power action is needed, one instance when this is useful is when a radio signal is transmitted out.

Är ju skillnad på spänning och effekt, detta kan uppfattas som att de likställs.



Detta bör förtydligas, vad gör induktorn? (filter)

Figure 3.9: Buck converter pinout
Source: `http://www.ti.com/lit/ds/symlink/tps62743.pdf`

3.9.1 Connections

Since the device incorporates a switching buck converter the output signal is lead through an inductance. This signal comes through the SW line. VOS takes the output signal as a feedback signal into the component. The EN pin

Output Voltage [V]	**VSEL1**	**VSEL2**	**VSEL3**
1.2	0	0	0
1.5	1	0	0
1.8	0	1	0
2.1	0	1	1
2.5	1	0	0
2.8	1	0	1
3.0	1	1	0
3.3	1	1	1

Table 3.1: Table showing the output voltages when setting each VSEL pin

is connected to supply voltage to have constant operation. One issue that occurs with this device is the fact that it cannot start up the MCU without supplying enough voltage, in this case, $1.8V$. As the system should have full control over the output voltage each one of the three selection lines is connected to the MCU. Before the MCU is set up all the pins is internally grounded, which then sets each of the selection lines to ground. By following Table 3.1 the output voltage when all the selection pins are grounded is just $1.2V$. This voltage will not start the MCU and thereby not starting the system.

3.9.2 Inverter

The buck converter needs to supply at least $1.8V$ to the MCU when the system is powered up. Table 3.1 shows that $1.8V$ output can be achieved by only setting VSEL2 pin high and leaving the others low. This task is taken care of by a simple logic inverter, driving the normal zero voltage "low" signal high. This is a simple component which only takes supply voltage, ground and inverts the VSEL2 signal feed through it. All the selection pins can still be controlled by the MCU to get the desired supply voltage to the system.

3.10 Battery

As the product is intended for different use cases and working environments the power consumption varies between them. One implementation like when used as a security product might only draw just a small amount of energy. Because it will only power on and sent transmissions if something happened if the product is moved. Compared to when used as a tracking device that sends radio transmissions sometimes a week or several times a day. Different batteries will most likely be used. To ensure that use of different batteries is easy, two battery connections are placed at the PCB, one having the same pitch and hole size as to fit a standard Japan Solderless Terminal (JST)-PH connector which is commonly used for different types of lithium cell batteries. The other connector is made for an ls-14250 battery. The battery comes in many different mounting solutions and this is a PCB purpose made with one small lead at each pole. This is a lithium battery which is half the size of a standard AA battery and has enough energy for most applications. The battery supplies the system with $3.7V$. This battery is widely used by the company in other products but with other connectors. The final board has the exact outer size as these batteries as to minimize unused space in the casing for the product.

4

Software

What is the step after a PCB is produced? It is time to test the system, and this is done with the help of a test program. This chapter will guide the reader through this process of setting up the processor to run program code. How all the components are programmed and tested will be explained in this chapter.

4.1 Programming

At the start of every embedded system, the processor has to be programmed. Here the most common implementation is the Joint Test Action Group (JTAG), where the all the programming and debugging is done through a standardized interface. The approach is different on this MCU, here three pins are used to program the device. The first one is the "PGC", which is the clock signal for the In-Circuit Debugger and "PGD", In-Circuit Serial Programming. The third pin needed from the processor is the MCLR. These pins on the processor have to be accessible to program the microcontroller. Ref.

the

4.2 Software implementation

is needed

The processor does not start up on it s own, much consideration ~~needs~~ in making right initialization and configure it right. A source voltage is supplied to the processor to get it to operate. There are some initial registers that need to be set in order to initialize and start the processor. This varies between different processors and models and is different for applications and systems. The first parameters that are necessary for this system are generated with the software, this to get the MCU to start without having to go through all the hassle of trying to figure these out. Information about the different aspects of each parameter is presented.

```
#pragma config FOSC = INTIO67
// Oscillator Selection bits
#pragma config PLLCFG = OFF
// 4X PLL Enable
#pragma config PRICLKEN = ON
// Primary clock enable bit
#pragma config FCMEN = OFF
// Fail-Safe Clock Monitor Enable bit
#pragma config IESO = OFF
// Internal/External Oscillator Switchover bit

// CONFIG3H
#pragma config CCP2MX = PORTC1
// CCP2 MUX bit
#pragma config PBADEN = ON
// PORTB A/D Enable bit
#pragma config CCP3MX = PORTB5
// P3A/CCP3 Mux bit
#pragma config HFOFST = ON
// HFINTOSC Fast Start-up
#pragma config T3CMX = PORTC0
// Timer3 Clock input mux bit
#pragma config P2BMX = PORTD2
// ECCP2 B output mux bit
#pragma config MCLRE = EXTMCLR
// MCLR Pin Enable bit

//// CONFIG4L
#pragma config STVREN = ON
// Stack Full/Underflow Reset Enable bit
#pragma config LVP = ON
// Single-Supply ICSP Enable bit
#pragma config XINST = ON
// Extended Instruction Set Enable bit
#pragma config DEBUG = ON
// Background Debug
```

Most of the MCU's connectors are then set up. There is one separate register for each of the A, B, C, D and E set of connectors. These registers contain information about the speed of the processor, how the connections should behave and which functions that should be activated or not. The direction of the data stream to or from the processor is done by setting the bits at the "TRIS" registers. Where a 1 is set as an input and 0 as an output. Internal pull up or pull down are done with the "LAT" registers. ~~Where~~ Here, 1 sets the connector idle high and 0 idle low. This processor sets all the inputs as analog connections initially when started. Where this system has no analog circuitry this is changed to enable all the inputs as digital. This is done by setting the all the ANSEL registers to 0. How all these settings are set can be seen below:

```
ANSELA = 0x00;
ANSELB = 0x00;
ANSELC = 0x00;
ANSELD = 0x00;
ANSELE = 0x00;

TRISA = 0b00000000;
LATA  = 0b10100000; // VSEL1 & VSEL2 & VSEL3

PORTB = 0b00000000;
TRISB = 0b11011111; // Acc_int, RTC_int, TCXO_EN,

                    //NIRQ_Radio, Hall_, PGC, PGD

//LATB  = 0b11111111; //?

TRISC = 0b00000001; // XTAL, SDN_RADIO, SPI, UART
LATC  = 0b00100000; // SND_radio

TRISD = 0b00000000; //
LATD  = 0b00101000; // CS_ACC & CS_Radio

TRISE = 0b00000000; //
LATE  = 0b10000000; // LED_RED
```

The oscillator is initialized right after, this is also done by writing to some specific registers. The first two oscillator control registers specify everything from the type of oscillator used, the frequency that the system is desired to run at and different power-managed modes. The "OSCTUNE" register is used to tune the frequency of the oscillator. Running the internal oscillator in the MCU in 1Mhz is set up with the following code:

```
OSCCON = 0x30;

OSCCON2 = 0x04;

OSCTUNE = 0x00;
```

4.2.1 SPI

To start SPI communication a convenient function is provided with this MCU. The function takes the desired speed, mode and when to read the command and writes the information in according registers.

4.2.2 LED's

Turning on Light-Emitting Diode (LED)'s is done by setting the according LAT register which will then pull the line high.

4.3 Radio implementation

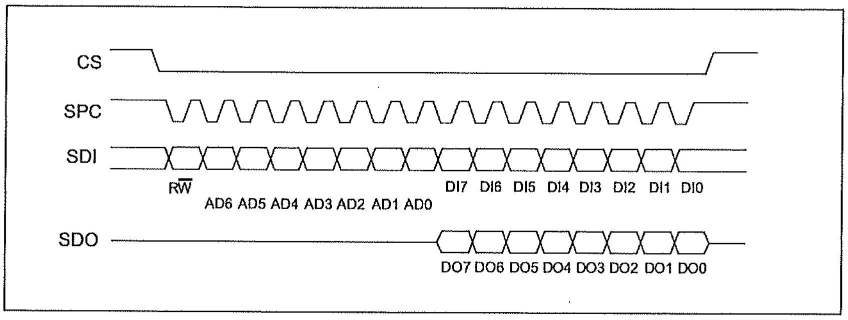
When first powered up, the radio is in the off state. To start the pin SDN is pulled low, and then high again. This allows the radio to power on. During the reset period, the radio cannot accept any SPI commands. Between each SPI command the Clear To Send (CTS) must be read. This is a function built into the chip to ensure that each command sent to it can be read properly. CTS is read by first sending the CTS instruction to the radio. Then the SPI bus is read until the radio is ready for next command and answers $0x44$ to the MCU.
To get a simple transmission several registers have to be written to, everything from the setting if the radio should send or receive, setting internal filters to what the GPIO pins should perform. There are about 30 rows with instructions that are sent to the radio. A working file with all the instructions is provided from earlier projects by the company. Some of the code is altered to enable most of the code to run for both the VHF and UHF frequency band. The differences between them are added between the code that is the same for them. With these parameters, the RF-switch is controlled. By setting the GPIO pins on the radio connected to the switch power and control over the switch is achieved. When the initial startup commands are set the radio is ready to send a simple radio pulse. The pulse is achieved by allowing the radio to send a continuous sine wave to the RF-switch. The RF-switch is then controlled by another register that sets the GPIO pins accordingly. These two registers can be accessed in $0x34$ and $0x13$. It stops the signal when the output sending is switched to an off state. The RF-switch is also turned off at this stage. This is done by writing to the same registers and switching modes and the values of the GPIO pins.

4.4 Hall sensor

The hall sensor is tested by reading the value on the output from the device. Reading an input at the processor is done by checking the value in the PORTB register. If the read value is 0 the sensor reacts to a nearby magnetic field.

4.5 Accelerometer implementation

The accelerometer communicates with SPI, this requires three wires that have to be considered in the code. The way the accelerometer communicates is by a simple read and write protocol. Between each read or write instruction the line accelerometer chip select need to be pulled high and then low again. To determine if data is read to the component or if data should be written to it the first bit in the first instruction consist of a special bit. The MSB determines between a read and write command sent to the accelerometer. When set, the following seven bits denotes which register should be accessed. Accordingly when not set the following seven bits denotes which register to read from. In Figure 4.1 from the product's datasheet it states how this communication is performed.



delarer

Figure 4.1: The prototype connection
Source: [10]

ordval

The simple code written to the accelerometer here is contained to read x,y, z values and a predictable answer to ensure it is working as intended. All these values are presented in the console. First, a command is sent to the component, "WHO_AM_I". When the accelerometer is working as it should it sends back the value 0x44, this to ensure it works properly. The speed that the accelerometer should perform the measurements it has to be set. The speed is set in the control register "CTRL1". To do this two commands is needed, one saying that this register should be written to and the other sets the measurement speed. The code that will perform this is shown below:

with

```
WriteSPI(0x20);      // CTRL1
WriteSPI(0x70);      // Gives the accelerometer 400Hz

WriteSPI(0x8F);      // Read from WHO_AM_I
Return = ReadSPI(); // Data is sent to Return
```

axis

Reading the values on each ~~axel~~ is done by reading from the OUT_X_L register. This particular component has a function that enables multiple readings from the chip. This makes reading subsequent register easier and is performed here. The component have a 16 bits resolution on the measurements but sends it in two eight bits at the time. First the lower half of the measurement is read then the other half. This can be seen below:

```
WriteSPI1(0xA8);         // "OUT_X_L"
X_L = ReadSPI();         // "OUT_X_H"
Y_L = ReadSPI();         // "OUT_Y_L"
Y_H = ReadSPI();         // "OUT_Y_H"
Z_L = ReadSPI();         // "OUT_Z_L"
Z_H = ReadSPI();         // "OUT_Z_H"
```

To get the final measurement number the lower part is shifted 8 bits and the other is added with boolean algebra.

4.6 Universal Asynchronous Receiver-Transmitter

Communication to a PC is achieved by enabling UART in the MCU. The code for enabling this has more or less been copied from earlier projects at the company. The function of the code is to enable the transmission, set the mode for the transmission and witch speed or boad rate it sends on.

stavn

4.7 PC software

The foundation for every development is a good development environment, both as the circuit boards are created and the software implementations needed later in the process. för

4.7.1 Solidworks PCB

Followit uses the PCB board design software Solidworks PCB from DASSAULT SYSTÈMES. It utilizes the industry-proven Altium design engine for layout and routing of printed circuit boards and combined with a close connection with the mechanical Computer-aided design (CAD) of classical Solidworks. With this program, the PCB layout and design can be transferred seamlessly over to the mechanical environment to create an exact case or enclosure for the circuit board. The version used in this thesis is 2018 Update 2.0 [6] is e

4.7.2 Orcad

For simulations on the filter for the VHF-band Orcad Capture together with Orcad Pspice is used. This is a great tool for making and setting up simulations of electrical circuits. The version used is a slightly scaled off version of that used by LTU. The version used is Orcad Lite 17.2 -2016.

4.7.3 MPLAB

Microchip which is the producer of the MCU used in this project has their own development environment which holds a lot of handy features when making a program for their products. The program is based on the open source NetBeans IDE from Oracle [4].

4.7.4 Assembly välj en

The actual code that runs on this processor is assembly, the most common hardware code which is used in almost all types of MCU's. Assembly is a hardware type language which means that it describes the actual process of the bites in a way for the human to understand. In the early days of computing, programming in Assembler was used to program almost any type of computer. These days, however, it is pretty much the preserve of embedded designers, particularly when using smaller 8-bit devices. [21]

4.7.5 C18

The C program is compiled with the compiler C18. This is the compiler which has been the official compiler for this particular processor. This compiler is used for all the processors in the family PIC18. This compiler is some years old and lacks some modern features. The version used in this project is 3.47.

5

Results

This chapter will guide the reader through the whole process of developing a system prototype. Designing the PCB, soldering the components, troubleshooting the board and writing the necessary code are some of the steps involved and they will all be described in detail here.

5.1 Schematics

The schematics over the circuit is created by placing all the components discussed earlier, every IC have a small number of components that are placed in a way so that it is easy to understand which components belong to which. A title is added to every part of the design for a good overview of the system. Since the section which included the radio is large it is placed on a separate page. When additional components are added in additional pages can be inserted. These schematics can be found in Figure 5.1 and Figure 5.2 .

kolla mening

Här har ju du gjort en hel del jobb, går det att beskriva på något sätt? Sen är ju komponenterna redan beskrivna, det behöver inte göras igen (men kanske pekas på).

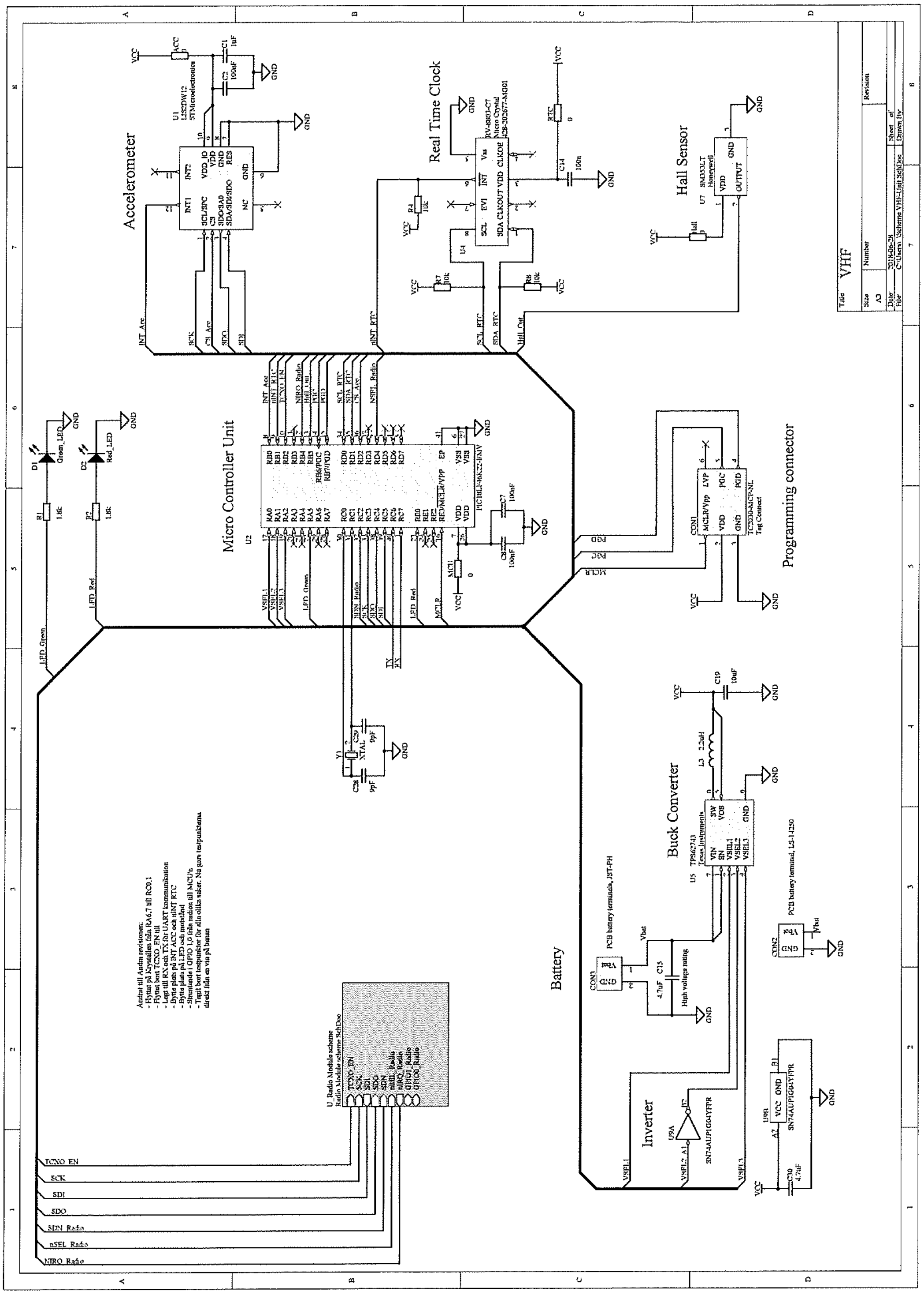


Figure 5.1: Schematic over the central parts of the circuit
Source: Author

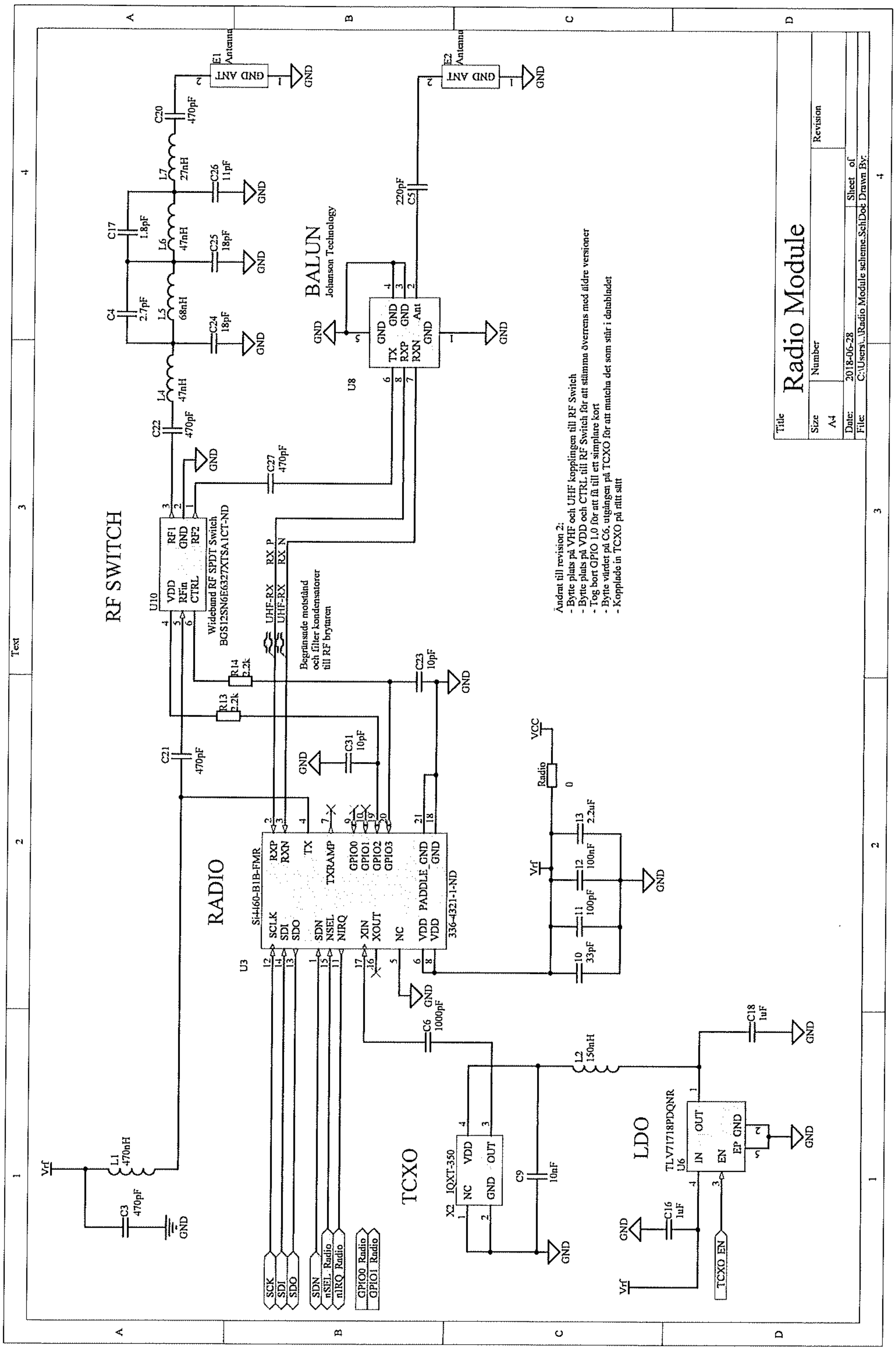


Figure 5.2: Schematic over the components and parts for the radio
Source: Author

5.2 First design

5.2.1 Layout

The first version of the boards are 35mm x 35mm in size. The different parts of the circuit are laid out in a way that it is easy to inspect and resolder if necessary. The main components of the board are placed close to each other at one side to get an idea of the design for the final product. This board is equipped with some test points for easy connections with test probes and oscilloscope. The silkscreen print on the top of the board was vague at some places and made distinguish them from each other hard. The VIA's connected to ground ~~is~~ covered in solder-resist not to any meaningful advantage but as a way of making the boards more visually pleasing. The pin one location used for aligning the components at one part could not be spotted. The footprint for the inverter was however wrong so this part could not be tested on this version of the board. A view of the board can be seen in Figure 5.3.

are

Känns konstlat.

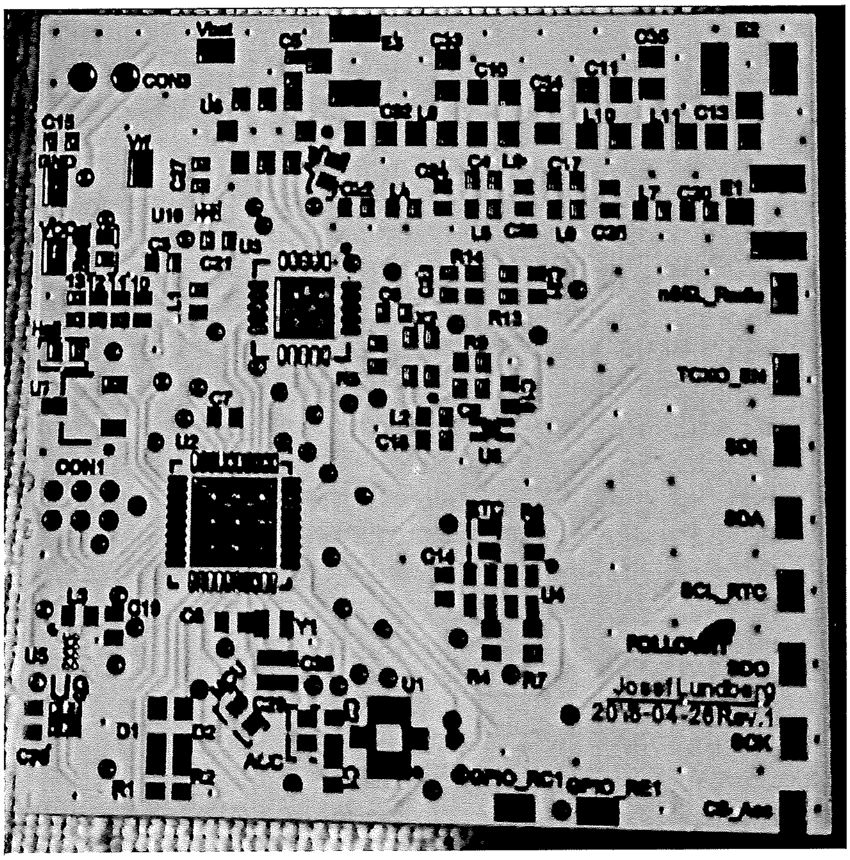


Figure 5.3: First (1) revision circuit board.
Source: Author

5.3 Communication

5.3.1 UART

The UART connection interfered with another connection which leads to one function not working as intended. ~~The function that is~~ the enabling line to

The erroneous part was

the LDO which powers the oscillator for the radio. It is fixed by connection of one of the extra pins that was laid out beforehand directly to the LDO. The transmitting half of the UART connection is working as intended on this version. Some of the resulting data which is sent to the computer can be seen in Figure 5.4.

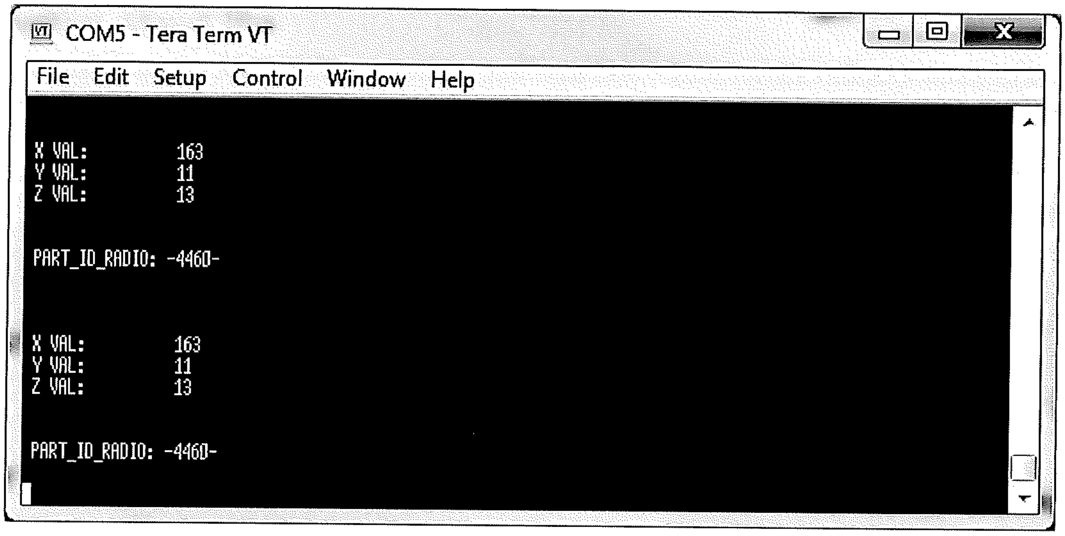


Figure 5.4: Simple UART transmission to a PC
Source: Author

5.3.2 SPI

However,

The SPI connection to the radio worked as intended. ~~But~~ no signal was received from the accelerometer. With a special footprint for the component, this would most likely be a source of problems. The actual connection should have worked but with the component not possibly have a good enough connection the connection could not be tested thoroughly. When connected to a separate evaluation board the accelerometer was able to communicate with the MCU using the same connections as the one on the board.

5.4 Second design

The second design is a made with all the knowledge learned in the first prototype. Improvements are made to every part of the product, both in the schematics, layout and the test code. This time the PCB'~~s~~ are ordered ready and assembled directly from the same company as the first PWB's. When dealing with Chinese manufacturers one has to be extra careful to give them precise~~ly~~ orders. With some questions back and forth both parts ended up happy and then the boards were produced. When received there were some in problems, however, ~~on~~ Of the 20 ordered boards only one had the RF-switch the right orientation and shorts were apparent in some of the buck converters. This resulted in extra work with the supposed to be finished boards.

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5.4.1 Schematics

From the first version some valuable point can be determined, both for the layout, schematics, and wiring. Improvements on the schematics are much based upon the visual representation. This is highly dependent on personal preferences, though it makes for a better view and easier visualization over the complete system. Some connections were moved to a better connector at the MCU. Some to get shorter and easier traces and some that interfered with other functions.

5.4.2 Layout

The layout is obviously changed dramatically to the ~~next~~ second version, but some improvements still imply. One change to the ~~next~~ second version is that some of the components are moved to the underside of the circuit board. This has a lot of benefits, besides the easier layout, it also helps the routing of traces and it ~~also~~ helps with the overall size of the board. On the first side of the board, the MCU is placed as well as the accelerometer, RTC, buck converter, programming pins, crystal oscillator and LED's. The LED's are placed close to the side to get good visibility from them regarding the orientation of the board in the casing. The most important test points are drawn out to the side for easy probe connections and convenience. These include the UART connections RX and TX. Both the serial interfaces, I^{2}C and SPI are also placed at the edges of the board.

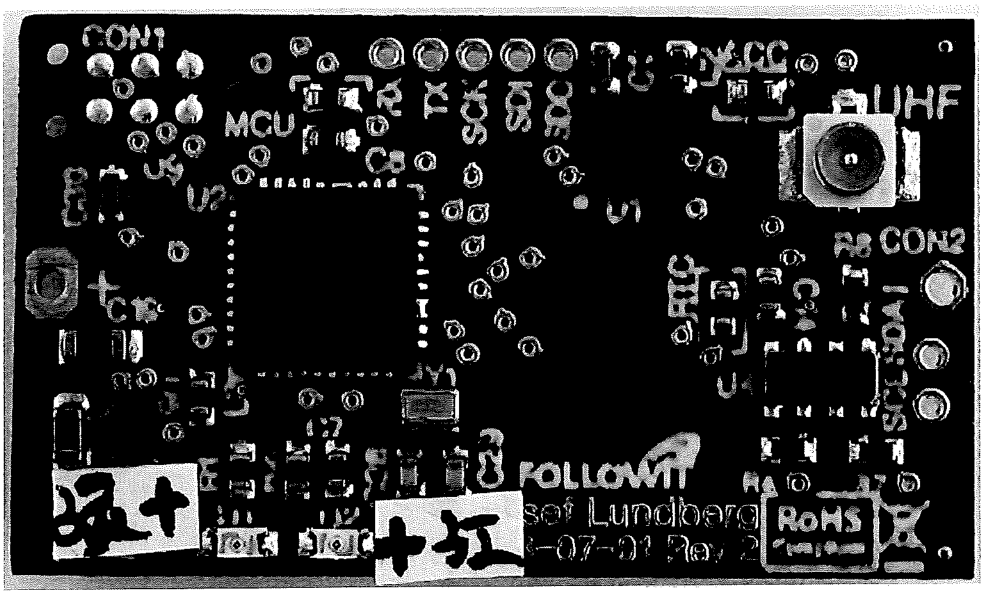

Figure 5.5: Top side of the second revision PCB
Source: Author

The other side is populated mostly with the radio module ~~and~~ all the necessary accessories that go with it. As well as both the filters, ldo, RF-switch and TCXO the hall-switch is also placed at this side of the board.

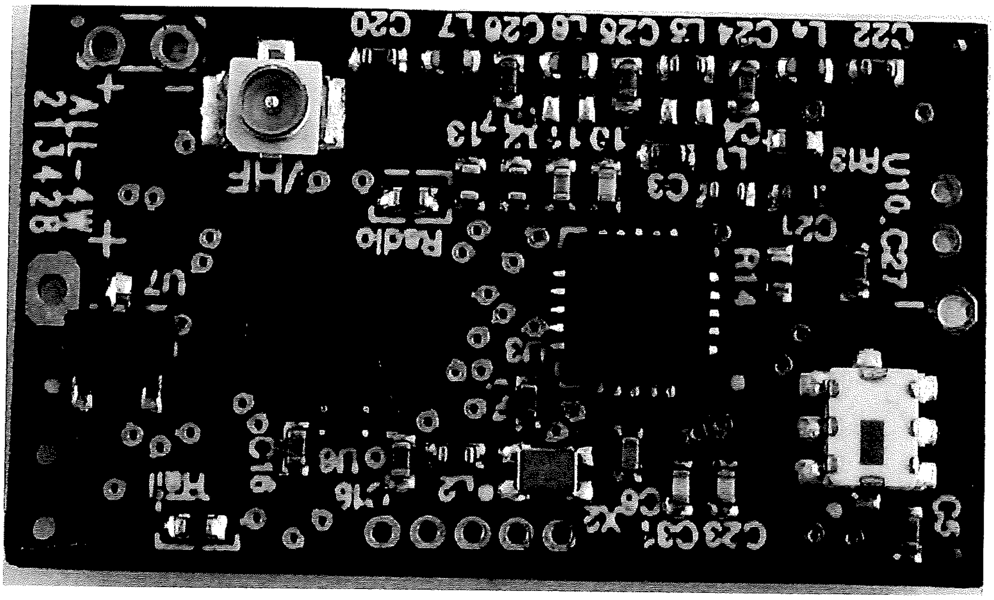

Figure 5.6: Bottom side of the second revision PCB
Source: Author

Resultat från test 2 ?

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Discussion

The first prototype could have been made directly using a company to place all the components, or the components should have been mounted with a pick and place machine to eliminate some initial troubleshooting and hassle regarding the soldering process. But with one of the project's goals to keep down also the process cost this was one part of that. This did, however, increase the understanding and personal expertise in the area with some great extent.
The test points were a good addition, they were frequently used and ~~was~~ were really useful when adding the hooks for the test probes to be attached to. Employees at the company did find them interesting for further use in future projects.
Additional test points would be a good idea. When the first board already had real estate to hold some additional points it should have been implemented.
The hardest bit with the system was the voltage adjusting buck converter. ~~Both~~ The fact that it was one of the smallest pieces which made it hard to solder, ~~C~~coupled with the fact that it has a Ball Grid Array(BGA) package meant that rework of this component was a big challenge.
Designing a PCB with white solder mask looks great and with black silkscreen, it was easy to see every marking. Problems did occur though; when visually inspecting the traces on the PCB it was hard, almost impossible, to see. It can be that the color used here was a thicker type that made it harder to see through or that white is used when the ability to see each trace is of less importance. With these things added together, I see why green is the most common choice for the solder resist on PCB's. The final design was therefore created with green solder mask and white silkscreen.
To ease troubleshooting more vias or exposed pads could be placed in every single transmission line, this to be able to read the voltage levels and data at every trace. When building the first revision some of the traces ~~was~~ were concealed under the solder resist. I found myself checking most of the traces with the oscilloscope or multimeter to read the values while troubleshooting. With the ones being hidden under the resist the probes needed to find the right legs of the MCU to perform the measurement. After both my designs there were small things that I knew were sub-optimal but did not put enough time or effort in fixing.

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Conclusion

A first prototype layout is created to test all the components and the connections between them. This was a bigger board to get easier access to all components. This version was hand soldered and did eventually work as intended. With this information, a final PCB design is then produced for the company. The design is tested thoroughly to work as expected with all the components that do what they should. Further investigations on Electromagnetic compatibility (EMC) and power consumption is not taken into account. A series of 20 pieces is produced which works to 90% and can be used by Followit to develop a program for the devices and further down the line sell these products. Development of a circuit board is not only time consuming but also difficult and a lot to account for. Even though it can appear to be an easy task to connect different traces and lines together on a PCB, many problems can arise that might not be easy to spot. This project involved many different types of problems, both with the design itself and also the components placement. When soldering these types of small Surface Mount Device (SMD) components by hand it is very easy to have a component that seems to have a good connection but can introduce big issues later down the line because of some pads not making the right connection. A lot of time has been dedicated to trying to get a component to work by writing code for it but in the end getting everything to work when the component is resoldered a number of times. And also the other way around, when a component had a perfect connection but the code for it was slightly wrong, a lot of time was put in to try to solder the component again. With this project, it was clear that a final board design is not generally developed on the first try. The process of making the first design as a prototype is a good way and made the development process easier than it otherwise would have been.

Skulle kunna vara discussion oxå.

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The project; complete with all software code, the application, hardware files and more, can be found online in the github-repo:
`https://github.com/Jurriz/VHF-Unit`