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Abstract

Surveillance and control have come a long way in the last years. Every new mobile phone, most cars, and smart watches have a Global Positioning System (GPS) tracing device built into it. 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 trucks and excavators.

Preface

I would like to thank the personal at Followit to taking me in and helping me through the project time. A special thanks to Bengt Evertsson for his supervision and help.
A big thanks goes to my supervisor Jonny Johansson at LTU for his support and guidance in the project. And a big thanks goes to my lovley fiancee Sara Andersson for her support and strong patience throughout the whole project.

Josef Lundberg
Lindesberg, May 24, 2018

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1

Abbrevations

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2

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.

2.1 Background

This is not a new area of products for Followit, different types of radio sending units have been made for over four decades now. 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. This is one of the reasons that this product is so sought for in the business.
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.

2.2 Project goals

Followit wants to produce a Very High Frequency (VHF) radio unit which has a powerful Microcontroller Unit (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 also 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 accessibilities.
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. There will be a study of the ways of making the product both small and cheap at the same time. The problem 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 of finding a good balance between the two is explained later in further detail.

2.3 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. The final PCB design will be delivered to the company for further programming and implementation. In case of time, a casing for the product as well as battery considerations will be made.

2.4 Approach

The idea that was presented to me 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
To get an understanding of all the parts and what there function are a list is constructed for a simple overview of the system.

- MCU - For processing data and connecting all the periferals together to a complete system.
- Accelerometer - Used for measuring movements. Important for knowing how much the device is moving or if lying still.
- Radio - All the communication to the outside world is done using radio transmissions.
- RF switch - To switch between two low pass filter antennas from a single output.
- Real time Clock - The best way to keep an exact time, used for the system to keep track of the time even after one year of constant operation.
- Hall switch - To turn on and off the device, a solution that is already used by the company.
- Programmable buck converter - To alternate the supply voltage for the system.
- Logical inverter - To invert the signal for the programmable buck converter.
- LDO - Supply the radio oscillator.
- Other components - Two LED's, two oscillators, one for the processor and one for the radio module.

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 datasheets 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 needs to be considered.
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 Serial Peripheral Interface (SPI) or Inter-Integrated Circuit (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 described later in this report. The code language used for this project is C.

3

Theory

This chapter will introduce the reader to the problem formulation and the underlaying principles taken into account. The priciple of radio communication and the important steps involved in developing a new product prototype will be presented. Basic information of the communication and programming will also be presented.

3.1 Prototyping

Much considerations is taken in orderto construct the final product. In this case the final prototype shoud be as small and inexpensive as possible. Some of the design elements of this prototype is directly related to this. Some basic criteriums for manufacturing is taken from the PCB suppliers website. These parameters is some industry standards and also from the manufacturers side the limitations for their equipment. Whitout going up in cost but keeping the cost down with no extra price these are the.

3.2 PCB

To get good characteristics of the circuit the system will be produced on a four-layer PCB. This have a lot of advatages over a standard two layer board. The four layer design will have a top layer where all the components will be placed, a bottom layer with extra room for tracing tracks and having another ground pylogon. The two inner layers consist of a power plane and a ground layer. Both for easier connecability 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.

3.3 Radio Frequency

Radio frequenzy are a set frequencies that is used for trancieving and receiving data wirelessly. Radio frequencies begins with at one end of the spectrum where the frequencies is about 100Hz. It contains all the frequencies up to 300Ghz. At 300Ghz the wavelength is 1mm long. Radio frequencies are divided into different bands, all with different caracteristics and areas of implementation.

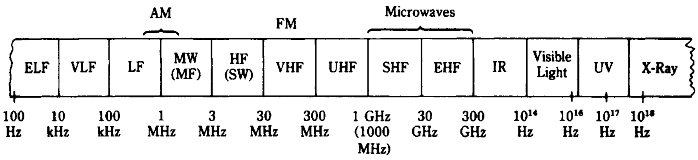

Figure 3.1: Electromagnitical frequencies
Source: RF Circuit Design [**?**]

Designing a circuit for radio transmission is a advanced and complex procediur. The high frequencies introduces a lot of intresting phenomenons that need to be considered when construction a circuit in these frequincies. When designing a circuit for RF the components and traces on the PCB behaives in a different way and takes on different characteristics than a equal system at lower frequencies. Some of the challenges that arises are described in "Secrets of RF Circuit Design". Stray capacitance is one of the phenomenon that arises when handlig RF. Between conductors, conductors to ground and between components a small capacitance occures when dealing with RF. To ensure a good radio signal some criterias need to be fulfilled. The output signal from the radio tranciever 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 trancievers the type used in this case is determined by the radio IC's manufacturer.
Another phenomena thats intruduces is the so called skin effect, where the "skin" part comes from the fysical phenomenal thats hapening. When the frequencies rises the resistance in conductors increases with it. The explanation to for this is that current choses the path of least resistance
Radio frequincies does many things to a board, these problems and apperances most be evaluated and considered.
"Secrets of RF Circuit Design"

3.3.1 Chebychev Filter

The chebychev type of filter is special in the fact that it have a steep fall rate and a high "Q". The Q factor is commonly used in filter design as a function of the length of the stopband through the whole passband. This makes it very suited for radio designs..
[14]
The class E (CLE) type used here uses switching type of The most intresting part of the class E is the fact that up to ideal power eficcianty can be acceived by constructed by this type. Class E makes use f
Stating in the datasheet to the radio IC the rough design aspects are defined. From

3.4 Radio component

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 trasmission used is the earlier explained class E. With this pice the class E is already implemented in the radio as this is widley used today and a very effective radio signal. The type of filter used for sending radio signals at VHF frequencies is defined in the defined

3.5 MicroControllerUnit

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 wich is a bit easier with The power consumption is higly dependent on the speed of which the processor is runnig, the faster the more power it consumes and also the slower the less current it will draw. And by the MCU beeing the component with the single higest power consumption the speed is set to a speed as low as possible. This low speed is not a concern in this particular system when the operations required is not time or speed sensitive. The voltage supplied to the MCU is another parameter that will alter the power consumption. The comonent 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 higer will damage the the part. To get the right speed of a crystal we need to get the right product for this particular case. As a crystal Many different types of oscillators exists, both internal and external types.

3.6 SPI

SPI communication is used to communicate between the MCU and other IC's on a circuit board. [**?**] The SPI is It uses four wires to communicate and additional one wire for each extra IC that is connected. The transmisson works in a synchronous serial maner where each bit is sent one at the time syncronous to a supplied clock signal. Different types of SPI exists but with the most common beeing the four-wire serial bus. SCL, SDO, SDI and SS is used

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

Eight bits are sent together to form a package of one byte. 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. The other mode selects the timing of data bits relative to the clock signal. Data is sampled either when the clock signal goes

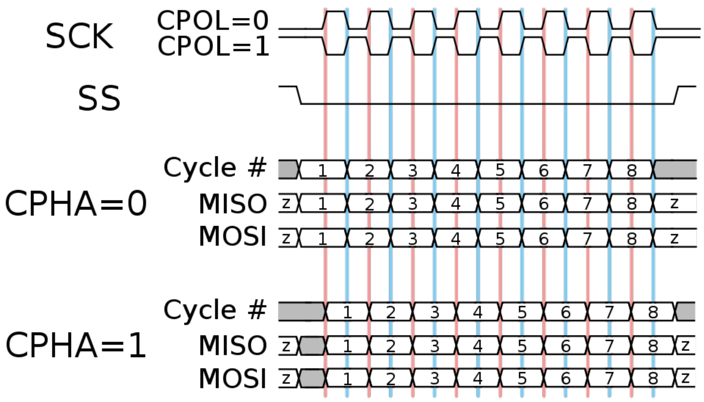

Figure 3.2: Timing and modes for a transmission over SPI
Source:
https://commons.wikimedia.org/wiki/File:SPI_timing_diagram.svg

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 induvidual slave select must be present. When set, only the choosen slave device is able to communicate. From the MCU's datasheet the following diagram show in Figure 3.3 how the connection works when connection several slave devices.

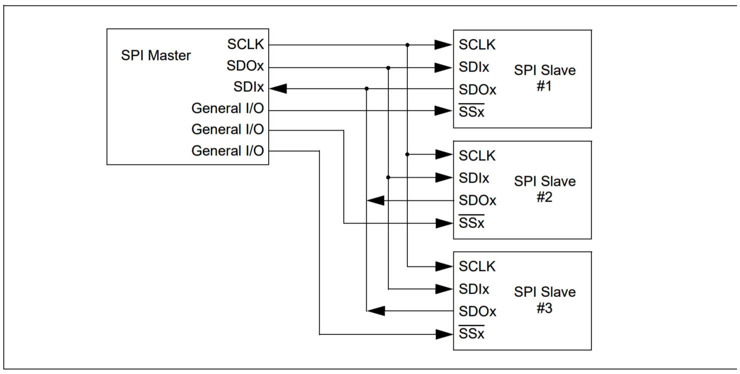

Figure 3.3: SPI master and multiple slave connections
Source:
http://ww1.microchip.com/downloads/en/DeviceDoc/40001412G.pdf

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.

3.7 I²C

4

Hardware

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.

4.1 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. These rules and constraints may differ from one supplier to another but as the company already 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.

- Trace width: minimum of 6 mils (0,1524mm)
- Via diameter: 10 mils
- Maximium thickness of board

4.1.1 Landgrid

The industry standard is always good to aim for, in this case, the basic designs are taken from IPC's design guidline[**?**]. While these are made for optimal manufacturability the footprints used on the test board are modified to enable for easier solderability, production and rework if needed. The land grids are made slightly bigger and longer to achieve this. The downside of making the pads larger is that the final board size increases and therefore the size of the land grids require to be reduced.

4.1.2 Easy prototyping

The components that are going to be used in high frequency often come in tiny packages. This gives the protypability problems with easy ability to solder and use, but the problem is that the best components used in this area of work will be small to fit in small advanced systems. To make a

4.2 Structure

The product is constructed with a number of components, which all have a central role in the final product. They can all be seen in Figure 4.1. A list of the major components and their function can be seen below:

- MCU: The central part of an integrated system, handles all the calculations and the program code.
- Radio: All the communications with the rest of the world will be handled by the radio, sending on the VHF and UHF band.
- 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 smoother voltage because no switching is taking place.
- 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.
- 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.

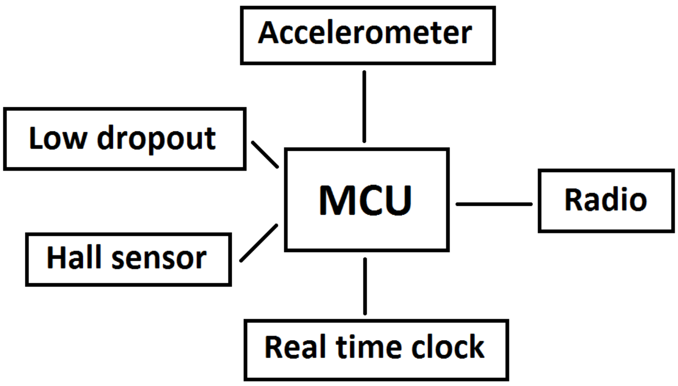

Figure 4.1: The prototype connection
Source: Aurthor

Each of the components of this project is carefully chosen to get the functionality and effect that the company is after. To ensure the system works as intended the company has acquired development boards to each of the components. Every component needs to be tested to ensure their individual functionality. Each development board is connected to the microcontrollers board.

First off, the MCU have to be set up in a correct way with all its parameters and then the other components could be connected and initialized one after another. The whole connection can be seen.

4.3 MicroController 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[3]. The version used is one with 40 pins. All the connections available are shown in Figure 4.2.

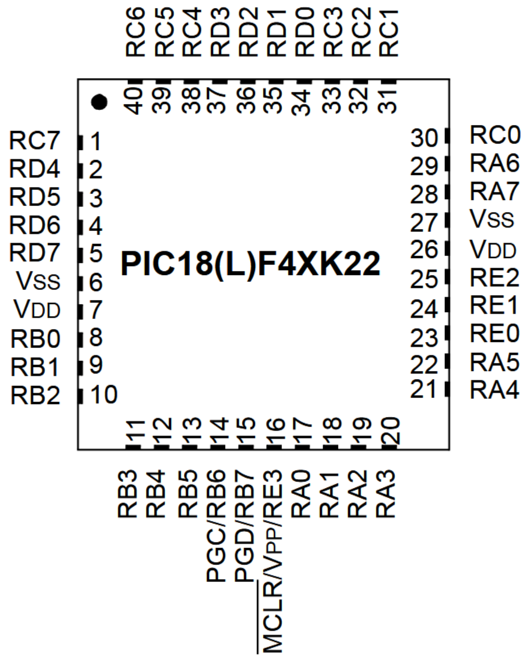

Figure 4.2: PIC18LF46K22 pinout
Source:
http://ww1.microchip.com/downloads/en/DeviceDoc/40001412G.pdf

4.3.1 Connections

4.3.2 Power

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.

4.3.3 Oscillator

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 external temperature compensated Crystal Oscillator (TCXO).

4.4 IMU

The motions of the system is measured with an 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 is very hard and fast movements in the product. One of the simplest IMU's is the 3-axis accelerometer, it

4.5 Accelerometer

The component used is a 3-axis, ultra-low-power and high-performance accelerometer from ST [1]. The component is the simplest of IMU's that this manufacturer has and this simplicity makes for a product that is only incorporate one single function. 3-axis accelerometer means that it can measure

4.6 Power

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.

4.6.1 Connenctions

4.6.2 Software implementation

4.7 Radio

4.7.1 Power

4.7.2 Connenctions

In the registers

4.7.3 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 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 (Update 2.0).

4.8 Power consumption

The total power consumption is calculated by adding the current draw from each individual component together. A different test is conducted to try different modes of the system. One describing the power consumption of only the processor. This is done by running it in an infinite loop with all the other components at the circuit powered down or in power down mode. Since the system is not supposed to be active just a small time with a longer power down mode in between the power consumption on the system has to account for a longer time span. The tests are made with a standard scheme used already by the company. The scheme consists of a small radio pulse every second and the system being inactive in between these radio pulses. All the systems

5

Software

What is the step after the 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.

5.1 Programming

In the start of every embedded system, the processor have 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.

5.2 Software implementation

The processor does not start up on it 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. These registers contain information about the speed of the processor.

5.3 Radio implementation

Radio Chip Waking Up First, the radio is in the off state. After the SDN pulled low, wakes up and performs a Power on. maximum of 6 ms (900 μ s room temperature) ready to receive commands on the SPI bus. The GPIO1 pin goes high when the radio is ready for receiving SPI commands. During the reset period, the radio cannot accept any SPI commands.

5.4 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.
(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) (PIC DESIGN)

5.4.1 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.

5.4.2 Assembly

The actual code that runs on this processor is assembly, the most common hardware code which is used in almost all types of MicroController units. Assembly is a hardware type language which means that describes the actual process for the

5.4.3 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)?

6

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.

6.1 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 in 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 **??**.

6.2 Layout

6.2.1 First design

The first of two boards is 3.5 times 3.5 mm 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 pin one location at one part could not be spotted. A view of the board can be seen in **??**.

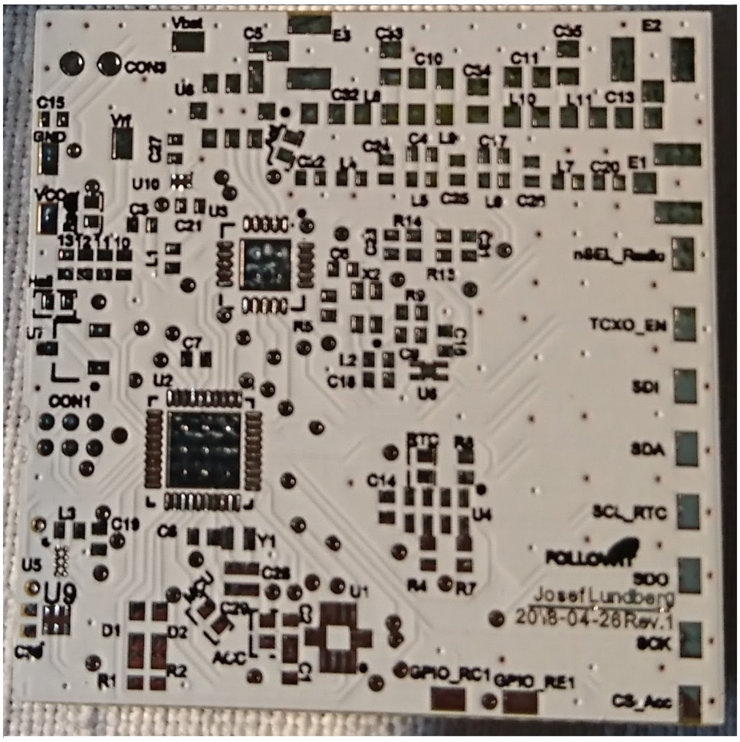

Figure 6.1: First (1) revision circuit board.
Source: Author

6.3 Communication

6.3.1 UART

The Universal asynchronous receiver-transmitter (UART) connection interfered with another connection which leads to one function not working as intended. The function that is the enabling line to the LDO which powers the oscillator for the radio. It is fixed by connection 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 6.2.

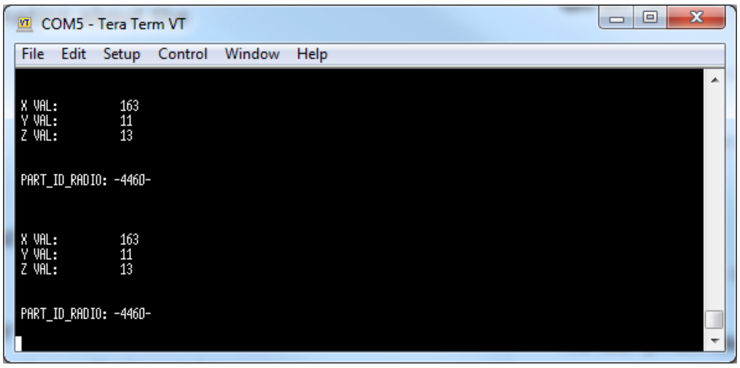

Figure 6.2: Simple UART transmission to a Personal Computer (PC)
Source: Aurthor

6.3.2 SPI

Testing started with both theMCU, radio and accelerometer soldered to the board. No communications were achieved when both of these slave devices were connected at the same time. After some troubleshooting, the failing factor of this is the accelerometer having it's SPI connection the other way around. The data out (SDO) line was connected to the data output, and the SDI was connected to the data input line of the accelerometer.

6.4 improvements

From the first version some valuable point can be determined, both for the layout, schematics, and wiring.

7

Schematics

To the PCB a schematic over the complete system has to be constructed. This is built by noting all the connections that were determined in earlier chapter. The complete system is split up in to two different schematics, one describing the Radio components and the other shows the processor and all the other parts.

8

Discussion

The prototype could have been made directly using a company to place all the components, or the components should have been mounted with a pic and place machine to eliminate some initial troubleshooting and hassle regarding the SMT process. But with one of the project's goals to keep down the process looked like this. This did, however, increase the understanding and personal expertise in the area.
The test points were a good addition, they were frequently used and employees at the company did find them interesting for further use in future projects. Additional test points would be a good idea. When the 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. Also the fact that it needed some adjustments in the form of 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. There is a reason that green is the most common choice. (The final design was therefore created with green solder mask)
To ease troubleshooting more a via 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 only some of the traces.

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[4] Silabs 4460 class E radio module http://www.classeradio.com/theory.htm.

[5] Silabs 4460 class E radio module http://www.classeradio.com/theory.htm.

[6] Silabs 4460 class E radio module http://www.classeradio.com/theory.htm.

[7] RV-8803-C7 Real Time clock from Micro Crystral http://www.classeradio.com/theory.htm.

[8] Voltage selecting buck converter from TI http://www.classeradio.com/theory.htm.

[9] Silabs 4460 class E radio module http://www.classeradio.com/theory.htm.

[10] Joseph J. Carr, *Secrets of RF Circuit Design*, McGraw-Hill/Tab Electronic, 2000

[11] Howard Johnson and Martin Graham, *High Speed Digital Design: A Handbook of Black Magic*, Prentice Hall, 1993

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Appendices

.1 Large Figures

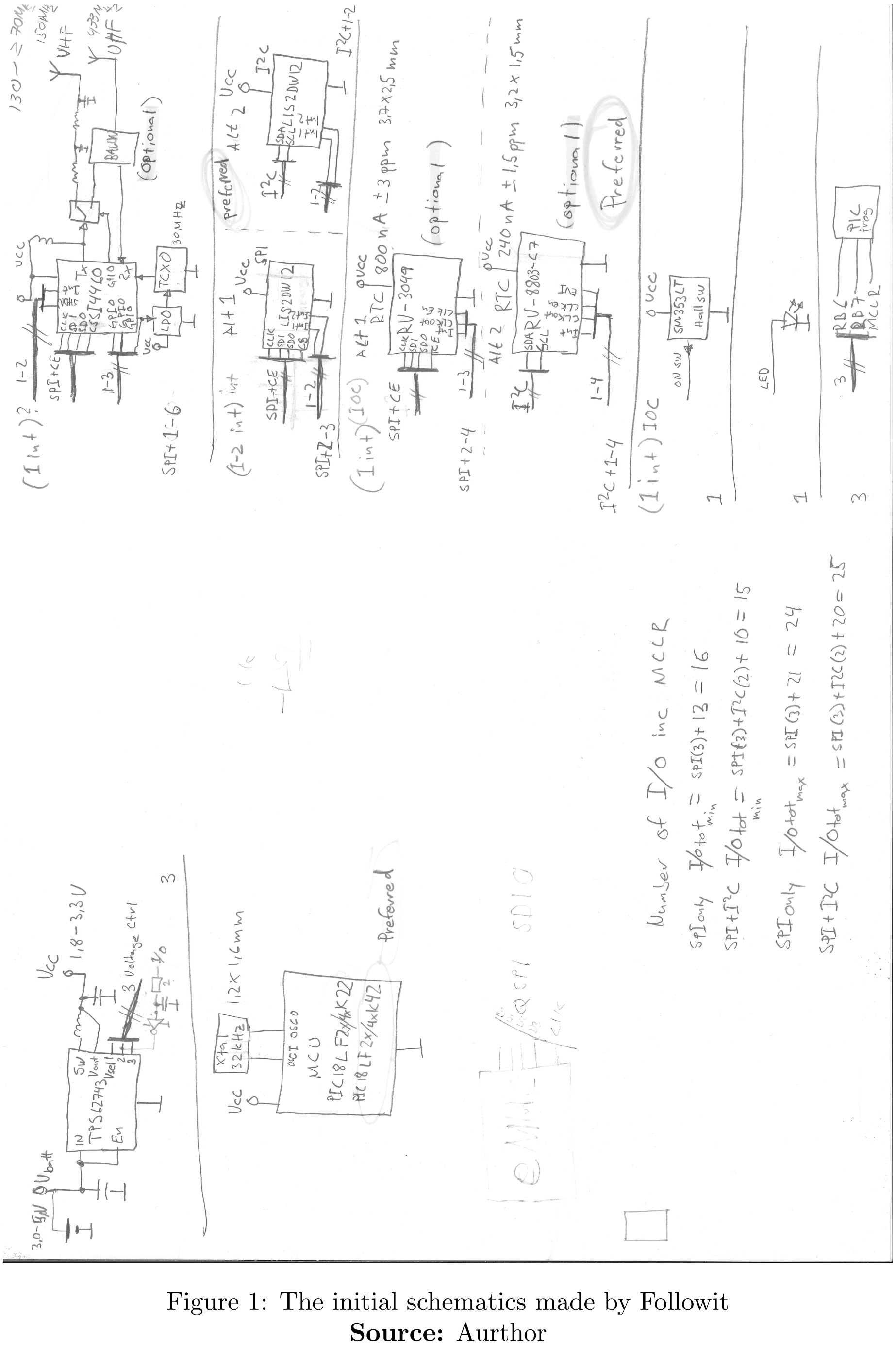

Figure 1: The initial schematics made by Followit
Source: Aurthor

.2 Lists

.2.1 Bill of Materials: Main PCB

Main Board Components	**Package**	**Quantity**
Capacitors:		
18p	0805	2
100n	0805	21
1u	0805	2
2.2u	0805	1
4.7u	0805	4
10u	Electrolytic SMD 5x5.3	6
Resistors:		
220	0805	1
1k	0805	2
1k	potentiometer	2

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