# Luleå University of Technology

## Dept. of Computer Science, Electrical and Space Engineering

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

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LULEÅ UNIVERSITY OF TECHNOLOGY

**Abstract**

Surveillance and control has come a long way the last years. Every new mobile phone, most cars and smart watches have a Global Positioning System (GPS) tracing device built in to it. Today it is hard to go anywhere without there beeing 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 GPS 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.

# Contents

# 1  Acronyms

**1. ADC** Analog-to-digital converter *Glossary:* ADC

**2. CAD** Computer-aided design *Glossary:* CAD

**3. DRC** Design Rule Check *Glossary:* DRC

**4. ERC** Electronic Rule Check *Glossary:* ERC

**5. GPIO** General Purpose Input Output *Glossary:* GPIO

**6. GPS** Global Positioning System 1, *Glossary:* GPS

**7. I$^2$C** Inter-Integrated Circuit *Glossary:* I$^2$C

**8. IC** Integrated Circuit 2, *Glossary:* IC

**9. IMU** Inertial Measurement Unit 6, *Glossary:* IMU

**10. IPC** Institute for Printed Circuits *Glossary:* IPC

**11. JTAG** Joint Test Action Group 8, *Glossary:* JTAG

**12. LDO** Low-dropout regulator 6, *Glossary:* LDO

**13. LED** Light-emitting diode *Glossary:* LED

**14. LGA** Land Grid Array *Glossary:* LGA

**15. LIB** Battery Management System *Glossary:* LIB

**16. MCU** Microcontroller Unit 6–8, *Glossary:* MCU

**17. NAME** Personal Computer *Glossary:* PC

**18. NMEA** National Marine Electronics Association standard *Glossary:* NMEA

**19. PCB** Printed Circuit Board 2, 3, 11, 15, *Glossary:* PCB

**20. PNG** Portable Network Graphics *Glossary:* PNG

**21. PTC** Positive Temperature Coefficient *Glossary:* PTC

**22. PWB** Printed Wire Board *Glossary:* PWB

**23. RTC** Real time clock 6, *Glossary:* RTC

**24. SEK** Swedish Krona *Glossary:* SEK

**25. SMD** Surface Mount Device *Glossary:* SMD

**26. SPI** Serial Peripheral Interface *Glossary:* SPI

**27. ST** STMicroelectronics *Glossary:* ST

**28. SWD** Serial Wire Debug *Glossary:* SWD

**29. TI** Texas Instruments Inc. *Glossary:* TI

**30. USB** Universal Serial Bus *Glossary:* USB

**31. via** vertical interconnect access *Glossary:* VIA

# 2 Glossary

**32. 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. 1

**33. IC** Integrated Circuit (IC) is a set of electronic circuits on one small flat chip. 2

**34. IMU** Inertial Measurement Units (IMUs) are integrated circuits that can measure acceleration, rotational velocity and magnetic field strength. 6

**35. JTAG** JTAG is an industry standard for verifying designs and testing printed circuit boards after manufacture. 8

**36. 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. 6

**37. MCU** A Microcontroller Unit (MCU) is a single computer chip designed for embedded applications. 6

**38. RTC** A Real time clock is an IC that is used to mesure time even when the main device is off. 6

# 3   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.

## 3.1   Background

This is not a new area of pruducts for Followit, they have made radio sending units for over four decades now. When new and improved technology arrives each and every year you need to make new products to have the latest most efficient and effective systems. Every generation of a component will most likley have a smaller physical size, have more advanced features and draw less power then the previous one. Followit wants to make a new unit which implement 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 GPS based 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 buisness. Most of the Integrated Circuit (IC)'s are already chosen by the company, but there are no acctual 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 a vehicles. This means that it Much consideration is taken to get the product both small and inexpencive. 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.

## 3.2   Project goals

Followit wants to produce a VHF radio unit which have a powerful MCU for advanced programs and with some extra feautures that makes 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 finalised product ready for marketing and sales.

Both the cost of the bare board and the components needs to be kept down. This require some special attention to the board design, 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 between making a prototype wich is tiny but have a high manufacturing cost and a inexpencive that have a bigger physical size. The procedure of finding a good balance between the to is explained further in detail.

A MCU - For processing Accelerometer - Important for knowing if the device is moving or lying still. Radio - All the communication uses the radio Real time Clock - Hall switch - To turn on and off the device

## 3.3   Scope

Main focus of this thesis is to create a PCB prototype that is tested and well designed and works as intended. Some of the coponents in the product are predefined but their implementation have to be done. Extended test code is written to the product which includes tests for all the components in the circuit. No documentation of the product is needed.

## 3.4   Approach

To get to the point of making the actual PCB a thorough analyse of the components and their connections needs 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 is crucial for operation and there might also be some peripherals connections and chip selection that needs to be considerd.
By writing a program the functions of each individual component can be tested. The code is written in C using the program MPLAB X[? ]. In some cases the component needs to be initialized in a specific way or it needs some other special attention which might require additional connections than it firstly seemed. With all the specified components connected together a program is made to show all the functions and that they work as intended. To ensure that each component on the PCB works and the prototype can be handed over to the software developers

# 4 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 speps involved in developing a new product prototype will be presented.

## 4.1 Prototyping

Much considerations is taken in orderto construct the final product. The project includes both the software implementation and also the hardware design. As the constrution of the board This chapter will describe the function of each element and their role in the complete project. This chapter

## 4.2 Prototyping

The final design is always the goal. 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.

## 4.3 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.

## 4.4 Radio Frequency

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 trancie ver 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 ICs 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.

[**?** ] 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

## 4.5   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.

## 4.6   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

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.

## 4.7   Accelerometer

EHEr

# 5  Method

The product is constructed with a number of components, which all have a central role of the final product. They can all be seen in Figure 1. A list of the major components and their function can be seen below:

- Microcontroller Unit (MCU): The central part of any 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 a accelerometer, this to determine if the unit is in motion or laying 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 aquire data at a specific set time. It is important that the clock is exact over the whole life of the pruduct.
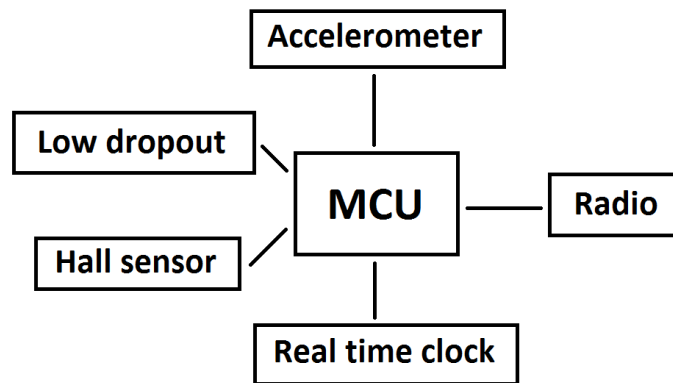


Figure 1: The prototype connection
**Source:** Aurthor

    Each of the components in this project is carfully chosen to get the functionallity and effect that the company is after. To ensure the system works as intended the company have aquired development boards to each of the components. Every components needs to be tested to ensure their induvidial functionallity. Each development board is connected to the micro controllers board. First off the MCU have to be set up in a correct way with all it parameters and then the other components could be connected and initilized one after another. The whole connection can be seen.

## 5.1 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 feautures. The particular processor used is the PIC18LF46K22[1]. The version used is one with 40 pins. All the connections avalible are shown in Figure 2.
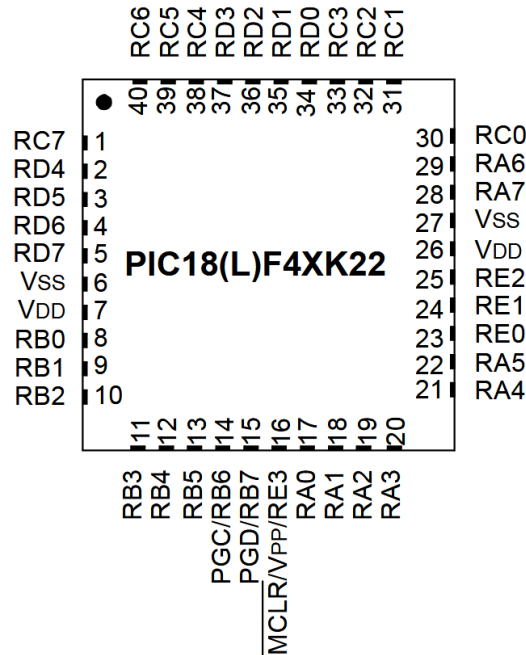


Figure 2: PIC18LF46K22 pinout
**Source:**
http://ww1.microchip.com/downloads/en/DeviceDoc/40001412G.pdf

### 5.1.1 Connenctions

#### 5.1.1.1 Power

Powering it is done by connnecting the VDD pins to the power net. Connected to 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 are choosen to 100nF.

#### 5.1.1.2 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 a external one. Where the external rely on a specific circuitry to provide the clock source. Examples of external oscillators are: clock modules, quarts 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 a external temperature compensated Crystal Oscillator (TCXO).

### 5.1.1.3   Programming

In 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.

### 5.1.2   Software implementation

The processor do not start up on it own, much consideration needs in making right initzilation and configure it right.

## 5.2   Accelerometer

The component used is a 3-axis, ultra-low-power and high performance accelerometer from ST[2].

### 5.2.1   Power

Two voltage connections is apperent on this device, one which is called VDD and the other is called VDD-IO.

### 5.2.2   Connenctions

### 5.2.3   Software implementation

## 5.3   Radio

### 5.3.1   Power

### 5.3.2   Connenctions

In the registers

### 5.3.3   Software implementation

Radio Chip Waking Up First, the radio is in the off state. After the SDN pin is pulled low, the radio wakes up and performs a Power on. Reset which takes a maximum of 6 ms (900 $\mu$ s typical at room temperature) until the chip is 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.

# 6 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.

# 7   PCB

# 8   Layout

Göra en egen design check list: med saker som måste vara med i en radiodesign

To get a 4 layer board some inintial rules needs to be setup. These parameters are set by the board manufactuer. The minimum measurements are presented in **??**

One is the width of the traces. minimum of 6 mils, which equals of 0,1524mm. Via diameter: 10

## 8.1   Landgridd

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

## 8.2   Easy prototyping

The components that going to be used in high frequency often comes 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

# References

[1] http://ww1.microchip.com/downloads/en/DeviceDoc/40001412G.pdf

[2] http://www.st.com/content/ccc/resource/technical/document/datasheet/group3/30/3a/4e/6b/68/16/4a/35/DM00323179/files/DM00323179.pdf/jcr:content/translations/en.DM00323179.pdf

# Appendices

## A    Large Figures

# B   Lists

## B.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