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RSSI-based Object Finding System

Bachelor's thesis (12 ECTP)

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Signaali tugevusel põhinev esemete otsimise süsteem

Lühikokkuvõte:

Selle lõputöö teemaks on süsteemi arendamine, mis aitaks signaali tugevuse põhjal leida eseme ja selle külge kinnitatud raadiosaatja. Töö annab üldise ülevaate raadiosageduste ja antennidega seotud teooriast ning raadioside tehnoloogiatest. Antud süsteemi realiseerimiseks valitakse esitletud teooria põhjal süsteemi parameetrid ja koostatakse süsteemi disain. Lisaks optimiseeritakse loodud disaini raadiosagedustel töötavaid osi, et tagada süsteemi parem toimimine.
Töö tulemusena valmib perioodiliselt andmeid edastav patareitoitega raadiosaatja, mis töötab sagedusel 433.92 MHz ja kasutab andmete edastamiseks amplituudmodulatsiooni. Lisaks disainitakse ja töötatakse välja andmete vastuvõtmiseks nutitelefoni micro-USB porti ühenduv raadiovastuvõtja, mis edastab saatjatelt saadud info ja mõõdetud signaalitugevuse nutitelefoni rakendusele.

Võtmesõnad:
Raadiosagedused, 433.92 MHz, amplituudmodulatsioon, MICRF112, MICRF219, ATTINY, vektor-võrguanalüsaator, Manchesteri kodeerimine.

CERCS: T170 Elektroonika

RSSI-based Object Finding System

Abstract:

In this thesis, work regarding to development a system that would help finding lost objects based on RSSI is presented. The thesis gives a basic overview of the theory behind RF modulation, antennas and PCB design. Based on the presented theory, the technology and system parameters are chosen to design and ultimately complete the system. To improve the performace of the system the RF parts of the circuits are optimized using a vector network analyzer.
As a result of this thesis a periodically transmitting battery-powered beacon that works at 433.92MHz is designed and completed. To read the transmitted data and the signal strength a receiver is also designed and completed to receive the data transmitted by the beacon and display the RSSI on a smart-phone screen using the micro-USB port.

Keywords:
RF modulation, 433.92MHZ, amplitude shift-keying, MICRF112, MICRF219, ATTINY, Vector-Network analyzer, Manchester coding.

CERCS: T170 Electronics

Contents

Abbreviations

RF - Radio frequency

IC - Integrated circuit

MCU - Microcontroller unit

USB - Universal Serial Bus

OTG - On-the-go

UART - Universal asynchronous receiver/transmitter

COM - Communication port

GND - Ground

LE - Low energy

BLE - Bluetooth Low Energy

IoT - Internet of Things

ISM - Industrial Scientific Medicine

GFSK - Gaussian Frequency Shift Keying

API - Application programming interface

RTLS - Real-time locating system

PAN - Personal area network

WPAN - Wireless personal area network

GSM - Global System for Mobile Communication

RSSI - Received signal strength indicator

LRC - Longitudinal redundancy check

VSWR - Voltage standing wave ratio

Introduction

The release of Bluetooth Low Energy has lead to a development of different products that allow finding your personal belongings by attaching a battery powered BLE beacon to them. These systems work using the built-in Bluetooth module of the smartphone to allow communicating with the beacon. Products like "The Tile" offer a maximum range of about 30 meters for communication.

The goal of this thesis is to develop a RF-based system as an alternative to Bluetooth Low Energy that could help finding an object using the received signal strength indicator. When developing a custom RF-based system it would be possible to achieve an improved range compared to the BLE devices.
To design a custom system using RF it is important to get an overview of the different technologies that can be used for that purpose. Also because antennas are an integral part of every system that uses radio frequencies for exchanging data, the basic theory and parameters of antennas is required to be explained. Based on the presented theory, parameters like the modulation type, system frequency, antennas and ICs can be chosen for the system. To improve the performance of the system a vector network analyzer and spectrum analyzer must be used to optimize and calculate component values for the RF parts of the circuit.

In the first part of the thesis the basic theory regarding RF modulation and antennas is explained. The second chapter gives an overview of existing RF technologies also including Bluetooth and discusses their suitability for object tracking. In the third chapter the initial system requirements are presented and the choice of system parameters is explained. The fourth chapter gives an overview of the designed system and the fifth chapter concentrates on optimizing the designed system. As the result of this thesis a periodically transmitting beacon and a smartphone attachable receiver are designed and tested. Additionally a custom packet exchange is implemented allowing to read the signature, temperature and battery voltage of the transmitting beacon.

RF theory

Basic digital modulation techniques

Modulation is the process of facilitating the transfer of information over a medium [15]. Digital modulation determines how the data transmitted over air is converted into the RF signal and back. Each modulation technique has different susceptibility to noise, technical requirements and power consumption.

Amplitude-Shift Keying

Amplitude-Shift keying (ASK) is a form of digital modulation that represents digital data as variations in the amplitude of the carrier signal [9]. For binary shift-keying the amplitude of the signal is changed between two levels to represent a binary bit value of "0" or "1". There also exist ASK techniques where the signal amplitude is changed between more than 2 levels but they are used rarely.

The technique where the amplitude of the signal is changed from zero to one hundred percent is called On-Off Keying (OOK) and is the simplest form of digital modulation. It is cheap to implement, but is very susceptible to noise, because any amplitude altering interference during the "0" signal corrupts the transmission. Switching a signal between a full-power signal and reduced power signal is simply referred to as ASK. Using a reduced power level instead of completely turning off the transmitter helps to combat the interference [28].

Modulating the amplitude of the signal means that the transmitting current at the reduced signal level is also lower. The power consumption of an OOK transmitter can be 50% lower than of a Frequency-Shift keying (FSK) or a Phase-Shift keying (PSK) transmitter [28].

ASK modulation can be described with formula:

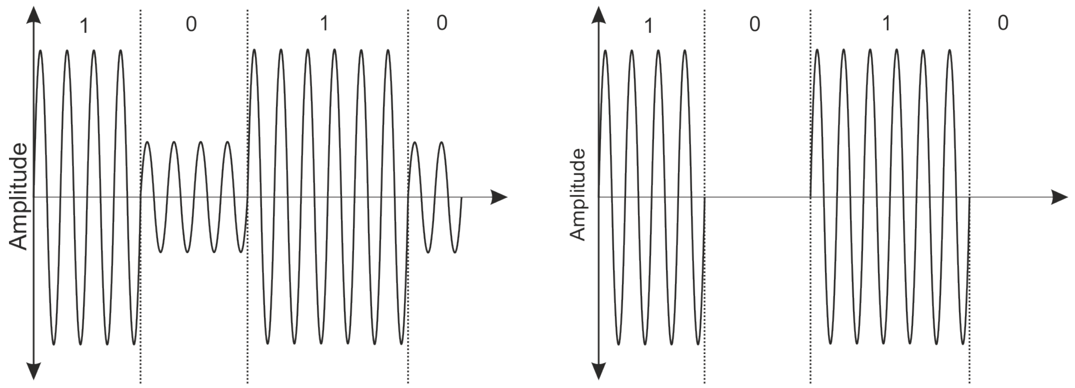
$$ASK(t) = s(t)sin(2\pi ft) \tag{1}$$

General advantages of ASK:

- Simple implementation and design
- Reduced battery drain

General disadvantages of ASK:

- More susceptible to noise



(a) ASK (b) OOK

Figure 1: ASK and OOK modulation techniques

Frequency-Shift Keying

Frequency-Shift Keying (FSK) is a form of digital modulation that represents digital data through discrete variations in the frequency of a carrier signal [10]. The implementation of FSK requires accurately setting the center frequency and frequency deviation for the receiver to properly decode the signal. One of the main advantages of FSK over ASK is that noise usually alters the amplitude of the signal not the frequency and therefore FSK provides better immunity to noise. But because FSK requires multiple frequencies to represent the binary values, the bandwidth is larger than ASK.

The following function describes the FSK modulated signal:

$$FSK(t) = \begin{cases} sin(2\Pi f_1 t) & for\ bit\ 1 \\ sin(2\Pi f_2 t) & for\ bit\ 0 \end{cases} \tag{2}$$

General advantages of FSK:

- More noise immune than ASK

General disadvantages of FSK:

- Requires a more complex design than ASK
- Theoretically requires a larger bandwidth than ASK [12]

In regular FSK there is no direct relationship between the bit-rate and the modulated signal and therefore discontinuities in the waveform can occur. Gaussian Frequency shift-keying solves this problem by passing the baseband signal through a gaussian filter, making the frequency transitions smooth and reducing the required amount of bandwidth [32].

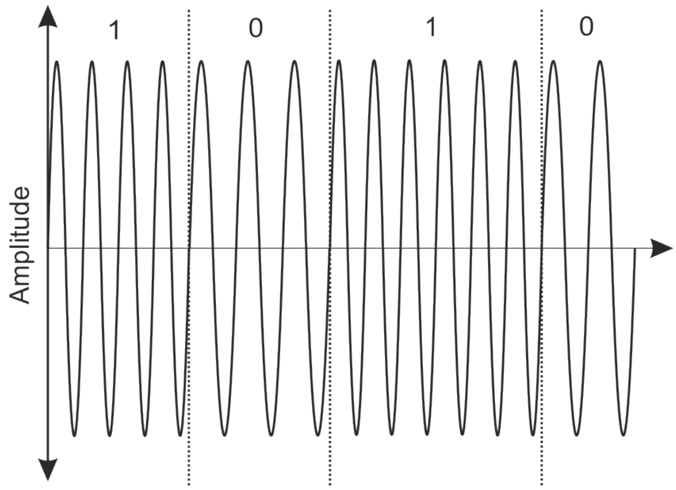


Figure 2: GFSK modulation

PSK

Phase-Shift Keying (PSK) is a form of digital modulation that represents digital data solely through discrete variations in the phase of a carrier signal [11].
Similarly to the FSK modulation, PSK is also much less susceptible to noise than ASK. But because PSK modulation works on a constant frequency it doesn't occupy as much bandwidth as FSK does. The most simple form of PSK is Binary-PSK which represents binary data with two signals with different phases. Besides Binary-PSK other types of PSK exist like the Differential-PSK and Quadrature-PSK.

General advantages of PSK:

- Requires smaller bandwidth than FSK and can use it more efficently than ASK or FSK [12]
- Less susceptible to noise than ASK

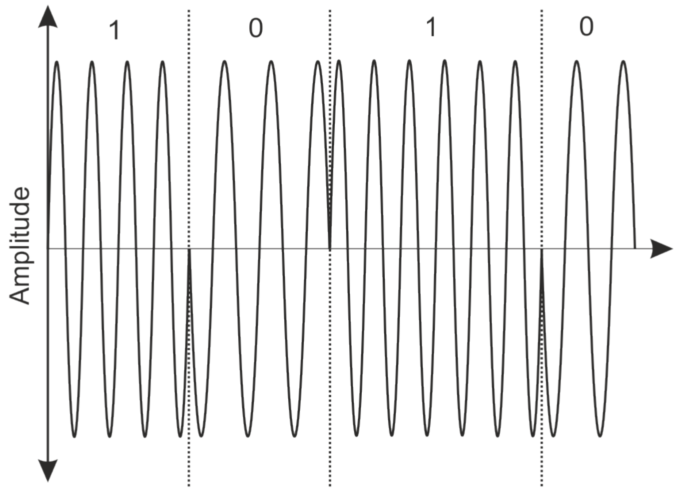


Figure 3: Binary-PSK modulation

- Excellent performance for higher data rates [28]

General disadvatages of PSK:

- Requires higher signal level and linear amplification [28]
- Limited by the ability of the device to detect changes in phase
- Implementing PSK can be more expensive than FSK and ASK due to its complexity

Antenna theory

A properly radiating antenna is a key aspect in RF system design. In this chapter some essential theory regarding antenna characteristics and different antenna types is presented.

Basic characteristics

Directivity

The directivity of an antenna is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions [4, 23].

$$Directivity = \frac{Maximum\ radiation\ intensity}{average\ radiation\ intensity} = \frac{U_{max}}{U_0} \tag{3}$$

Gain

The ability of the antenna to direct input power into particular direction is characterized by gain. It is similar to the directivity, but also takes the efficiency of the antenna into account. The gain is defined as "the ratio of intensity, in a given direction, and the radiation intensity of the reference antenna that obtains the same power" [4]. In most cases the reference antenna is a isotropic radiator antenna, that is a hypothetical "one point" antenna, that radiates equally in all directions and therefore is 100% efficent [23]. In most cases, when the direction is not stated, the gain is calculated in relation to the direction, where the maximum power is radiated for both the given antenna and reference antenna. Gain is measured in dB and if there is a desire to point out that gain is measured with respect to an isotropic antenna, then it is marked as dBi.

$$Gain = efficiency \times directivity \tag{4}$$

Bandwidth

The bandwidth of an antenna shows in which frequencies can the antenna operate properly. Bandwidth is more important for antennas that are bigger in measurements than quarter-wavelength, where the performance depends greatly on the bandwidth and the input signal frequency.

Input impedance

Like any other conductor, an antenna has a capacitive and inductive resistance to alternating current. The input impedance of an antenna is defined as: "the impedance presented by an antenna at its terminals" [4].

Electrical transmission system, the SWR (standing-wave ratio) is a measure of how efficiently RF power is transmitter from the signal-power source, through the transmission line, into the load [29].

Antenna types

There are many different antenna types and they all have different characteristics. The most important parameters to consider, when choosing an antenna are the bandwidth, gain, directional pattern, efficieny and also input impedance. Besides the antenna characteristics the other important things to take into account are the antenna placement, occurence magnetic fields on the PCB and size of the ground plane. Following chapters describe the most suitable antenna types to be used for small scale devices.

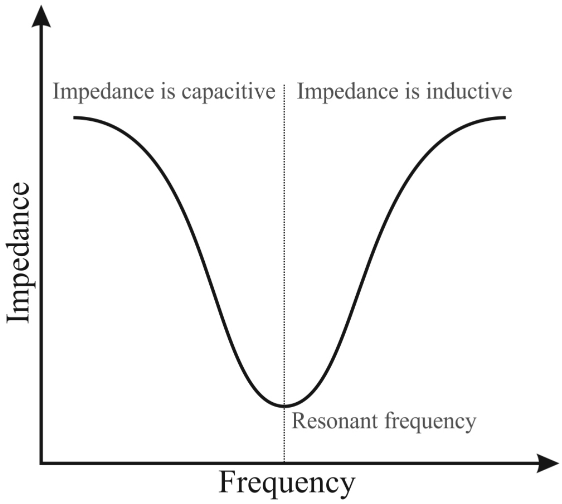
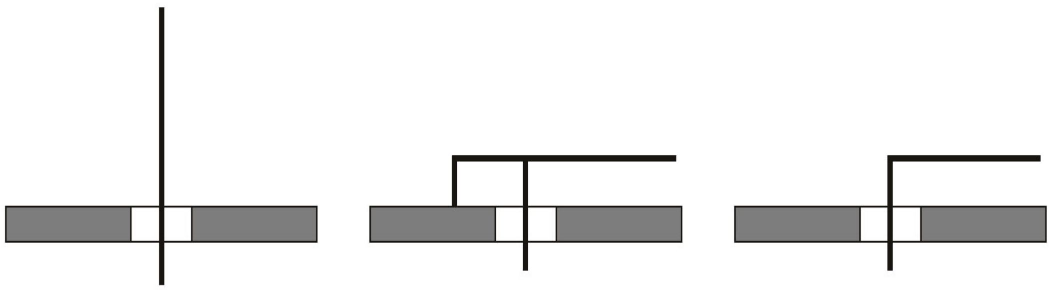


Figure 4: Input impedance of an antenna

Wire antenna

A wire or also known as the whip antenna is a monopole antenna, which most commonly refers to a quarter-wavelength antenna. A quarter-wavelength monopole antenna behaves as a half-wavelength dipole antenna thanks to the ground plane being the other quarter-wavelength element in the monopole antenna [34]. This means, that a proper groundplane is needed for best performance.



(a) Monopole (b) Inverted F (c) Inverted L

Figure 5: Wire antenna types

Microstrip antenna

An antenna that is formed by a PCB trace with certain pattern is called a microstrip antenna.
Advantages:

- Manufacturing costs are low, because the antenna is a part of the PCB anyway.

- Has a very thin profile.

- If the antenna is properly designed, it can have a very large bandwidth [16].

Disdvantages:

- Is unsuitable if the available PCB area is small, as there must be a reasonable clearance between the antenna trace and ground plane [16].

- A microstrip antenna can be easily detuned by the presence of a human body or a nearby metal object.

- Getting the proper center frequency requires multiple manufacturing cycles.

- Any changes on the PCB can easly affect the center frequency.

Chip antenna

The chip antenna is an antenna made for small-scale applications. In the domain of small antennas a chip antenna is the main alternative to the microstrip antenna. Advantages:

- Is a stand-alone component and available in different sizes and configurations

- Nearby objects don't detune the antenna as easly as the would detune the microstrip antenna [16].

- Flexible tuning and testing options.

- The PCB area required for the antenna is smaller than for microstrip antenna.

Disdvantages:

- Costs more than the microstrip antenna.

- Efficiency is not very high and is typically in the range of 10% - 50% [3].

PCB and circuit design considerations

50 ohm transmission line

The transmission line is the connecting link between the antenna and the receiver of transmitter device. Its purpose is to carry RF power from one place to another as efficiently as possible. To avoid power loss the RF trace measurements on the PCB can be calculated to be 50-ohms.
A common RF transmission line that can be used on a regular 2-layer PCBs is the coplanar waveguide.

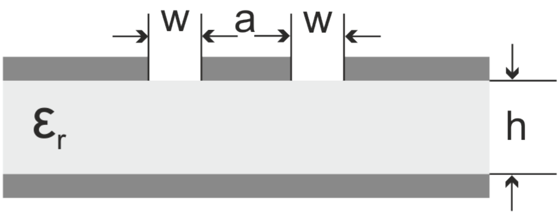


Figure 6: Coplanar Waveguide

The impedance of coplanar waveguide can be calculated with the following equations: [33]

$$Z_0 = \frac{60.0\pi}{\sqrt{\varepsilon_{eff}}} \frac{1.0}{\frac{K(k))}{K(k')} + \frac{K(kl))}{K(kl')}} \quad (5)$$

$$k = a/b \quad (6)$$

$$k' = \sqrt{1.0 - k^2} \quad (7)$$

$$k' = \sqrt{1.0 - k^2} \quad (8)$$

$$kl = \frac{tanh(\frac{\pi a}{4.0h}))}{tanh(\frac{\pi b}{4.0h}))} \quad (9)$$

$$\varepsilon_{eff} = \frac{1.0 + \varepsilon_r \frac{K(k'))}{K(k)} + \frac{K(kl))}{K(kl')}}{1.0 + \frac{K(k'))}{K(k)} \frac{K(kl))}{K(kl')}} \quad (10)$$

where

a is the width of the track

b is the sum of the width of the track and gaps on either side

$\boldsymbol{\varepsilon_r}$ is the relative dielectric constant of the dielectric

h is the thickness of the dielectric

PI-filter

To attenuate unwanted harmonics a low-pass filter must be used to pass compliance testing. One such filter can be the PI-type filter which composes of two shunt capacitors and one series inductor. For 50-ohm termination impedance a 3dB ripple Chebychev low-pass filter can be used. The filter capacitor and inductor values can be calculated with the following equations: [31]

$$\omega_c \approx \omega_{RF} * (\frac{1}{1 - 0.1333}) \tag{11}$$

$$L = \frac{35.6}{\omega_c} \tag{12}$$

$$C = \frac{0.067}{\omega_c} \tag{13}$$

where

$\omega_c = 2\pi f_c$ where f_c is the cut-off frequency

$\omega_{RF} = 2\pi f_{RF}$ where f_{RF} is the transmitter frequency

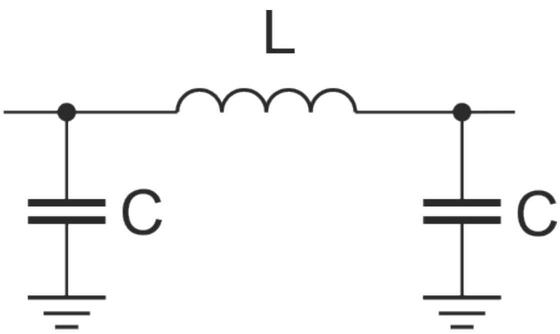


Figure 7: Low-pass PI-filter

Manchester coding

Manchester coding is one of the most common data codings used today and it can be used for transferring data using a RF modulated signal [19]. This coding technique provides the means to add the clock signal to the transmitted data and allows recovering the bit values without the presence of a separate clock signal. Manchester coding provides a benefit of always having the average DC level of 50%. One drawback of the Manchester coding is that the encoded data-rate must be two times higher than the original data-rate.

For encoding the data all the bits with a value "1" are replaced with a transition from zero to one and all "0" values are replaced with a transition from one to zero. This way the clock can be recovered from the bit transitions and a separate clock signal is not necessary.

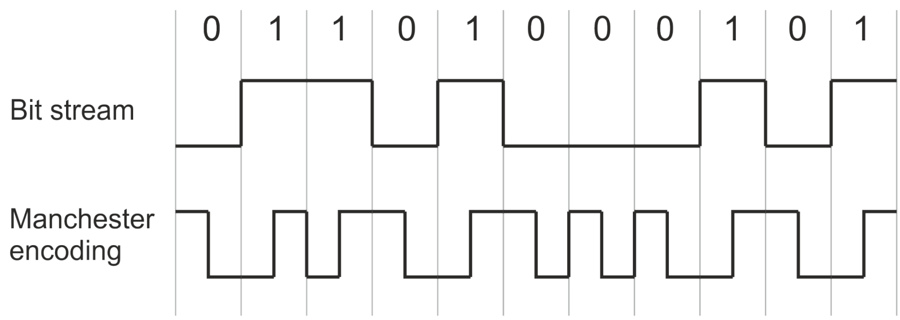


Figure 8: Manchester encoding

Regulations

The regulations on the use of RF devices in the European Union are based on the recommendations by the Electronic Communications Committee (ECC). The application of the transmitting device also determines the applied regulations on the device. Low power wireless devices are generally refered to as short-range devices and these are the limits regarding non-specific short range devices: [20]

Frequency Band	ERP	Duty cycle	Channel Bandwidth
433.05 – 434.79 MHz	+10dBm	<10%	No limits
433.05 – 434.79 MHz	0dBm	No limits	No limits
433.05 – 434.79 MHz	+10dBm	No limits	<25kHz
868 - 868.6 MHz	+14dBm	<1%	No limits
868.7 - 869.2 MHz	+14dBm	<0.1%	No limits
869.3 - 869.4 MHz	+10dBm	No limits	< 25 kHz
869.4 - 869.65 MHz	+27dBm	<10%	<25 kHz
869.7 - 870 MHz	+7dBm	No limits	No limits
2400 - 2483.5 MHz	+7.85dBm	No limits	No limits

The value ERP stands for effective radiated power which indicates the output power of the transmitter, plus the antenna gain and minus the signal chain losses. The duty cycle is defined as the maximum total time that the transmitter is switched on expressed as a percentage of the total time in a one hour period. [20]

Existing RF technologies

Large majority of the systems associated with object identification and tracking are RF based and use wireless technologies like RFID or Bluetooth. The following chapters briefly describe the existing RF technologies, applications and their suitability for object tracking and identification.

RFID

Radio Frequency Identification (RFID) is a technology that allows reading an unique ID from a RFID tag. The technology is being used in supply chain management, door access cards, product security tags, toll payment collection and object tracking [13]. A RFID tag can perform similar tasks like the magnetic strip or the barcode except it can hold more data and it can fulfill both read and write functionalities. Some RFID devices also provide possibilities to secure the data transmission.

An RFID system is composed of a compatible tag and a reader which support the same standards. RFID tags can be divided into two main classes: active and passive tags. Active tags require a stable power source to operate and passive tags receive their power from the electromagnetic field of an RFID reader. Passive tags can be read from a distance of 10 centimetres to a few metres and the active tags can have a "read" range of even 100 metres [13].

RFID standards

RFID devices are based on different standards that have been developed for separate frequencies and applications mainly by two organisations: The International Organization of Standards (ISO) and Electronics Product Code Global Incorporated (EPC).

The 18000 series ISO standards for the RFID technology define the air interface standards for the most commonly used RFID frequencies:

- ISO 18000-1 - Generic parameters for air interfaces working at different frequencies

- ISO 18000-2 - Air interface for 135 KHz
- ISO 18000-3 - Air interface for 13.56 MHz
- ISO 18000-4 - Air interface for 2.45 GHz
- ISO 18000-5 - Air interface for 5.8 GHz
- ISO 18000-6 - Air interface for 860 MHz to 930 MHz
- ISO 18000-7 - Air interface for 433.92 MHz

Additional standards include:

- ISO 15693 which is a standard for vicinity cards that can be read from distances up to 1,5 meters.
- ISO 14443 contactless integrated circuit cards which is also the basis for NFC technology
- ISO 7816 is related to electronic identification cards with contacts.
- ISO 11784 & 11785 regulate the RFID tagging of animals (extended by ISO 14223).
- ISO 24730 defines the air interface and an API for RTLS systems

Besides the ISO standards, EPCglobal has developed air interface protocol "UHF Gen2" defines the logical and physical requirements for an RFID system of a reader and a passive tag that operate in the 860 - 960 MHz range. In this standard the tags receive all their power from the readers RF signal. The communication is half-duplex and the reader receives data by transmitting a continuous wave to the tag while the tag responds by modulating the reflection coefficient of it's antenna [14].

RFID tags

The reading range of an RFID tag is determined by the reader and also the tag being active or passive. Parameters like the operating frequency, antenna size and sensitivity also have an effect on the reading range of the tag. Here are some examples of the existing active and passive RFID tags.

- **HID global** offers a very wide range of passive tags for a variety of applications like asset tracking and logistics, medical, laundry and transport items each supporting the nescessary standards. For example a Logi Tag 161 for harsh enviroments works on 13.56MHz (supports ISO 15693 and ISO 18000-3), has 16 mm diameter, 1024 bits of read and write memory and can be read from up to 34 cm [26]. A tag from the same company called the Brick tag operates on 860MHz to 960MHz (compliant with EPC C1 G2 and ISO 18000-6C) and is about the same size, but can be read from up to 2,5 meters [26].
- The active tag offered by **Omni-ID** called the Power 415 operates on the 433 MHz frequency using FSK modulation and can be read from up to 400 meters. This tag can be used for asset tracking in harsh enviroments. The air interface protocol being used is IEEE 802.15.4 and it's battery can last up to 5 years. [24]

Conclusion

While passive RFID tags provide good possibilities for object identification, they aren't well suited for object tracking. Most passive tags have a low reading range (under 10 meters) beacause they need to receive power from the reader. Also they might require multiple readers to efficiently determine the location of the tag.

Active tags however have better reading range but don't have any specific standards applied. The concept of an active tag doesn't specify the protocols or the network infrastructure being used. Some tags use RFID over WIFI and others employ the IEEE 802.15.4 standards. This means that a custom solution can be built using only the concept of an active RFID tag.

Bluetooth

Bluetooth was created in 1994 to provide an wireless alternative to exchanging data via cables [35]. The specification is managed by the The Bluetooth Special Interest Group.

Bluetooth versions

Classic Bluetooth Classic Bluetooth (versions 3.0 and lower) works in the 2.4GHz ISM band and provides 79 channels for packet excahange in most countries [6]. All channels have a bandwidth of 1 MHz and the data modulation scheme being used is GFSK [17]. To minimize the effects of channel intereference Bluetooth employes the frequency hopping technique doing 1600 hops per second [6]. Basic Bluetooth supports a bit rate of 1 Mbps while Bluetooth version 2.1 Enhanced

Data Rate supports a bit rate of 2 Mbps. Most common uses of Classic Bluetooth so far has been audio streaming, which is used in wireless headsets and speakers or for streaming music to your car stereo system [35]. Streaming a signal or sending a file requires a high continous data rate and also consumes power while not exchanging data to keep the connection alive.

Bluetooth Low Energy BLE (Bluetooth V4.0+) was created for applications involving the IoT where a high continuous data rate isn't nescessary and the data is transferred in bursts at certain intervals. Minimal BLE packet data payload is 2 bytes and the maximum is 39 bytes [17]. BLE uses the same modulation scheme as the classic Bluetooth using 40 channels, each 2MHz wide which allows using simpler radio chipsets than Classic Bluetooth [17]. Because BLE uses only 3 advertising channels it requires up to 1.2ms in to scan them in contrary to Classic Bluetooth which needs 22.5ms to scan all 32 advertising channels [5]. Therefore a successful BLE packet transfer (scanning for devices, linking, sending data, authenticating and terminating) can be completed in just 3 milliseconds, allowing the transmitter radio to go to a deep sleep mode after that [17].

Using BLE for a battery powered devices means, that a coin-cell powered device can broadcast data at intervals for extended periods of time. Bluetooth Low Energy is well suited to be used in RSSI based object tracking thanks to it's low power usage and low latency.

Bluetooth object tracking

Bluetooth Low Energy has made possible the development of devices that can assist finding lost objects. Many smartphones today support Bluetooth Low Energy and systems can be built using the communications and low power usage provided by this technology. Here are some products using Bluetooth Low Energy for finding lost objects.

The Tile

Tile is a BLE based device which helps a user to find their belongings using their smartphone, as shown in Fig. 9. User can find the Tile beacon by RSSI or by play a loud tune triggered from the smartphone app [30]. It features a 100-foot radius, 1-year battery life. The smartphone app has a map of the last know locations of the beacon and can help find stolen or lost object with the help of other Tile application users. It uses a PCB antenna and a CR2032 battery as the power source. A pack of one Tile retails at 24.99$ on Amazon.

Pixie

Pixie is a company that provides yet another solution to finding objects, but does it in a different way than other Bluetooth Low-Energy beacons. The company has developed a Location of Things (LoT) platform and claims that it can accurately

Figure 9: The Tile

locate objects in a 3D space. The system consists of 4 Pixie Points (beacons) that communicate with each other allowing to calculate the distances to each other and ultimately provide the data for calculating their locations in relation to the smartphone. A Pixie Point (beacon) has a range of up to 150 feet, locating accuracy of 1 inch and 1.5 year of battery life [25]. A pack of 4 Pixie Points is sold for 69.95$

More technologies

IEEE 802.15.4 and ZigBee

IEEE 802.15.4 is a standard that defines the physical layer (PHY) and media access control (MAC) and has become a standard for creating RF-based Personal Area Networks. The standard was created as alternative to Bluetooth and high datarate WPAN to provide short range, low bit-rate and low cost wireless PAN. It defines the physical layer with a PSK transceiver capable of datarates up to 250kbits per second. [1]
ZigBee standard enhances the IEEE 802.15.4 by providing a simple networking layer and standard application profiles. It can operate on two different ISM frequency bands: 915 MHz and 2.4 GHz. The network layer of ZigBee supports star, tree and mesh topologies and has three device roles: coordinator, router and end device. A coordinator establishes a ZigBee network while only the end devices can enter sleep mode.
A common ZigBee module on market is the **XBee** by the Digi International. XBee Standard programmable module has RF transmit power of +8 dBm in boost mode and claimed indoor/urban range of 80 meters and line-of-sight range of 1200 meters. In the boost mode the device consumes 59 mA in while transmitting and 45 mA while receiving. [36]

ZigBee technology is most suitable for connecting wireless sensors, instrumentation and control systems, but can also be used for RSSI based object tracking. Thanks to the netwoking layer provided by ZigBee object localisation can be perfomed with a network of devices. For example RTLS experiments conducted in Computer Science and Information Engineering Department of Cheng Shiu University have shown to get 0.7 meter accuracy in an 15x15 meter area using 12 nodes [18].

Other

GSM networks also provide mobile tracking systems by collecting antenna data and pinpointing the location of the mobile device from the signal strengths of the antennas. This technique is used by mobile service providers over the world.

Using **GPS** positsioning along with GSM can be used for sending the GPS coordinates of the device through the mobile network, which can be used for tracking vehicles or animals.

WiFi signal strengths can also be used for object tracking and RTLS by setting up a network of routers or using existing network infrastructure. Devices can postition themselves in this network by scanning for nearby routers and calculating their positions based on the signal strengths. Exactly this kind of tracking solutions are provided by companies Accuware and Ekahau.

Requirements & technology

The main goal of the system is to assist finding objects based on RF signal strength. To achieve this, a transmitting device must be attached to the object and a compatible receiver is required to receive the signal and measure the signal strength.

Initial requirements

Designing a RF based system requires choosing the most suitable technology for the given purpose. Finding objects based on RSSI requires frequent enough RSSI readings and a transmitting beacon that could work on battery power for extended periods.
Here are the inital system requirements:

- The system must assist finding an object in the range of at least 10 meters
- The transmitter device must be battery-powered and should work for at least a month without changing the battery
- The transmitter should be small enough to be comfortably attached to a keyring
- The receiver should be able to read the RSSI for one transmitter every two seconds or more often

Additional requirements depend on the type of technology and solution being used for the task.

Creating a RF system

The steps required to create a custom RF system are the following:

- Choosing the RF technology and whether to use any standard based solutions

- Designing the circuits
- Testing the circuits and optimizing the RF parts of the circuits
- Completing the software and implementing the packet exchange
- Creating the user-interface

Choosing the technology

The working principle of the system requires only identifing and detecting the transmitter by it's signature and measuring the RSSI of the received packet.
Because similar solutions that use Bluetooth Low-Energy already exist it was decided not to use this technology. Other technologies like ZigBee provide somewhat overly complicated network structure for this task and require a two-way communication.
Building a custom solution upon the concept of an active RFID tag can provide a way to identify the object and measure the signal strength of the identification packet. Relying on the packet being periodically sent by the tag means that the tag could only transmit and isn't required to receive any data. Using this kind of solution means that the system could compose of a battery-powered transmitter and a receiver which must provide some indication of how far the tag is.
To provide a user interface and more functionality to the system, it was chosen that the receiver would be designed to be attachable to an Android smartphone via the micro-USB port. This way the receiver would receive power from the USB port and it would be possible to develop an Android application to provide UI for the system.

Custom RF link

These are the key aspects of designing a custom RF link:

1. **Choosing the working frequency(band)** in correspondence with available ICs on the market
2. **Choosing the digital modulation technique** (ASK,FSK,GFSK etc.) in correspondence with available ICs on the market
3. **Choosing the RF ICs** (also choose wheter to use ICs with an integrated MCU or an external MCU)
4. **Choosing what type of antennas to use** (wire antenna, chip antenna or PCB antenna)

And for current system the following options were selected:

1. As pointed earlier the Electronic Communications Committee in Europe defines three possible frequencies for non-specific short-range devices: 433.05 – 434.79MHz, 868 - 870MHz, 2400–2483.5MHz. The frequency chosen for this system was 433.92MHz to provide maximum range as the path loss for lower frequencies is smaller [7].

2. It was chosen to use ASK as the modulation scheme, because it is simple to implement and it's current consumption for the same transmitting power can be smaller than the current consumption of FSK or PSK.

3. Out of the available transmitter and receiver ICs that work at 433.92MHz and support ASK modulation, chips from the company Micrel were used. More precisely MICRF112 for transmitting and MICRF219A for receiving raw-data. Both the transmitter and the receiver ICs were chosen from the same manufacturer, so that they would certainly work when paired.

4. Because an efficent omni-directional PCB antenna is hard to create and requires multiple productions cycles to achieve the required performance, this technology was not used. Instead, chip antennas were selected for both the transmitter and the receiver due their small size and the simplicity of implementation. Still, if the chip antennas wouldn't perform as excpected it is possible to replace them with a whip antenna.

System overview

Working principle

The system is composed of a custom receiver and one or more periodically transmitting beacons that work at 433.92MHz.
The beacon transmits a manchester-encoded packet each second containing it's unique signature, battery voltage and temperature. The receiver then detects the packet and validates the data before forwarding the packet contents and the RSSI measurement to the Android device via the USB connection.

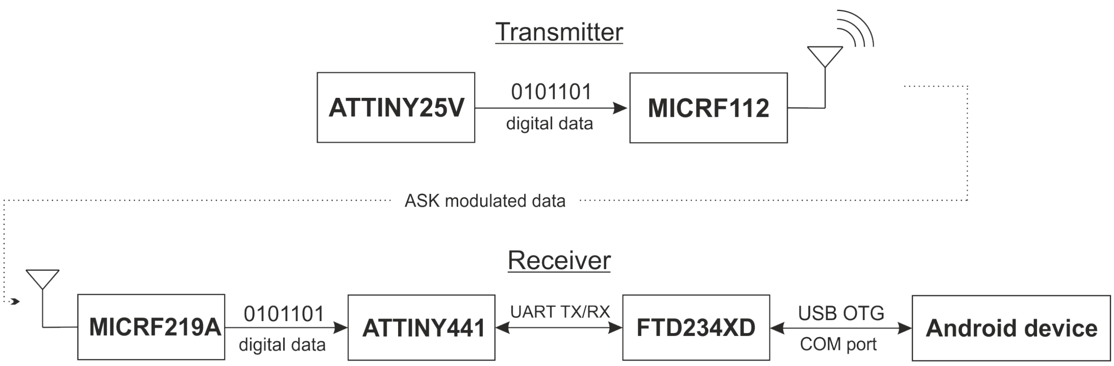


Figure 10: Simplified system working principle

The transmitter uses the Atmel ATTINY25V MCU that wakes up from the power-down mode after a second long interval, turns on the MICRF112 for transmitting it's signature along with other data and then returns to power-down mode.
The receiver is only active when it's connected to a micro-USB port. The MICRF219A data-output pin is read by the Atmel ATTINY441 MCU. The MCU detects the packet and reads the analogue RSSI of the MICRF219A. If the received packet is valid, the MCU sends the packet contents and the RSSI reading through the UART interface to the FT234XD which forwards it to the Android device through the virtual COM-port.

Packet structure

The 8-byte advertising packet being sent by the transmitter is composed of a sync word, preamble, 3-byte signature value, LRC, temperature reading, battery voltage and another LRC. Description of the packet contents:

Figure 11: Advertising paket structure

- The sync word is for the receiver IC to adjust to the signal and to allow the decoder to sync with the transmitted data. It is always equal to "0b10101010".
- The preamble designates the start of the packet and is equal to "0b00000011".
- The device signature is composed of a 3-byte value which adds up to $2^{3*8} \approx$ 16 *million* different IDs.
- The one-byte LRC is the result of XOR'ing all the signature bytes and indicates wheter the three received signature bytes were valid.
- The temperature is a one byte signed integer value that allows sending temperatures ranging from -127 to 127°C.
- Vbat is a 4-byte value which designates the battery voltage as follows: 0x0 = 1.8V, 0x1 = 1,9V . . . 14 = 3,2V and the value 0xF equals a voltage above 3.2V.
- The final 4-byte LRC is calculated by XOR'ing the V_{bat} and two 4-byte parts of the temperature value.

Beacon design

The transmitting beacon is a battery-powered device, that periodically transmits packets containing it's signature, temperature and battery voltage at the frequency 433.92MHz.

Schematics & components

All of the active components were selected so that the circuit would work using voltages as low as 1.8V to use as much of the capacity of a CR2032 battery as possible. To protect the circuit from inserting the battery backwards and avoid exposing the voltage to reverse circuit a P-Channel MOSFET was added to the power supply line.

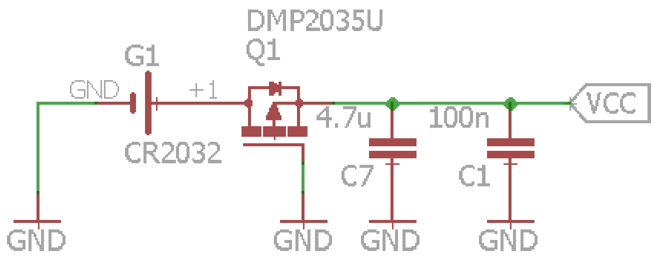


Figure 12: Transmitter power section design

The transmitter uses MICRF112 IC as the RF modulator. MICRF112 is a true "Data-In, RF-Out" chip with 10dBm transmitting power into a 50 ohm load [21]. This chip was chosen mainly due to the simplicity of the implementation and also because the datasheet provides an application circuit with given compomenent values for the antenna matching network. The maximum data-rate of the MICRF112 is 50 kbps [21]. MICRF112 requires a reference frequency from a crystal oscillator to set the carrying frequency.

The crystal frequency can be calculated by dividing the carrier frequency by 32 and which in our case equals 13.56MHz [21]. The IC can work at voltages from 1.8V to 3.6V meaning that a CR2032 battery is suitable for powering the circuit [21]. As seen in the schematic on Figure 13, the MICRF112 is controlled by the MCU using 2 pins: EN - pin for enabling the chip (using a pull-down resistor) and also the ASK pin which acts as the data input of the device.

The components L1, C5, C11, L2, C6 of the transmitter output network were derived using the VNA and the process of doing so is explained in the chapter "Optimizing the RF circuit"

The chip antenna being used is Rainsun AN1603-433 which has input impedance

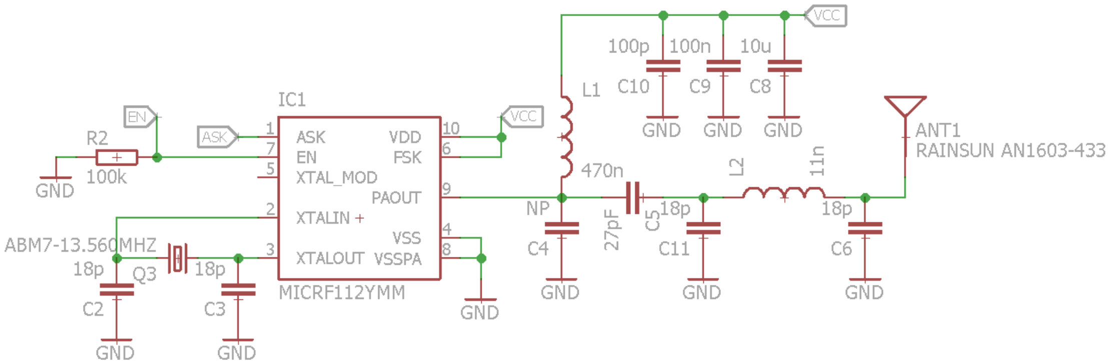


Figure 13: Transmitting section design

of 50 ohm which means, it requires only matching the circuit output to 50 ohms. The antenna is an omni-directional antenna and provides 0.5dBi peak gain [2]. The antennas center frequency is 433MHz and bandwidth is 8MHz, which means that it can be also used at our frequency 433.92MHz [2]. The maximum Voltage Standing Wave Ratio is 2.0 which means, that up to 11% of the power sent to the antenna can be reflected back [2].

The central controller of the transmitter is an Atmel ATTINY25V 8-bit MCU which manages the power cycles, composing packets and outputting data to the RF chip. Additionally it reads the battery voltage and does temperature measurements. The MCU works at 4MHz to allow working at voltages down to 1.8V. The ATTINY25V is programmable via the serial interface with the Atmel AVR MKII programmer.

The full schematic of the transmitter is added in appendices.

PCB design

The PCB was designed to hold a replaceable CR2032 battery on one side and have the electrical components on the other side. The size of the PCB is 25x30mm and the board thickness without components is 1 mm.
For the given board thickness the RF trace width and clearance from GND plane was calculated to be 50 ohms according to coplanar waveguide calculation Equations (5) to (10).
The ground plane cut-out near the antenna seen on figure 14 was designed to improve the antenna performance as placing the antenna too near to ground can negatively affect it's radiating properties.

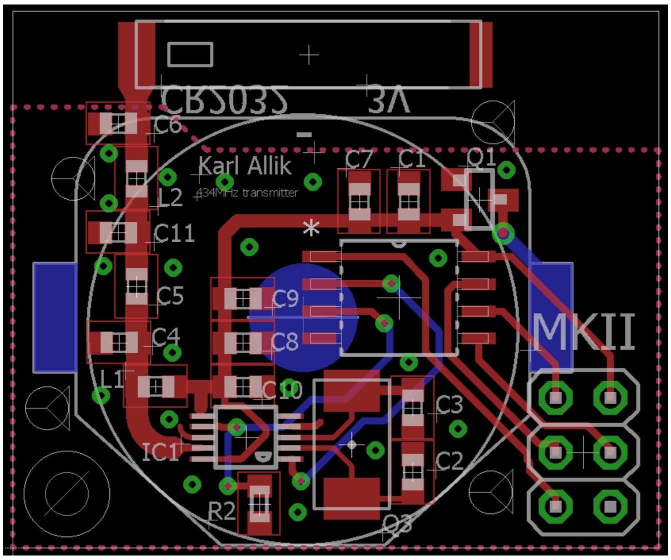


Figure 14: PCB routing of the transmitter

The design includes the central MCU Atmel ATTINY25V, RF modulator Micrel MICRF112 plus the suitable crystal oscillator for it, RainSun AN1603-433 chip antenna and the 50-ohm matching network composed of multiple passive components. Additionally the design includes a P-Channel MOSFET for reverse current protection, a CR2032 battery holder and a 2x3 pin-header for programming the ATTINY with an Atmel MKII programmer. The PCB also has mounting holes for the possibility to mount the PCB into an enclosure.

Software

The main task of the transmitter is to compose packets containing the unique signature of the device, battery voltage and temperature of device. Also a vital part of this device is to manage the power state of the transmitter IC and also control the power consumption of the device.

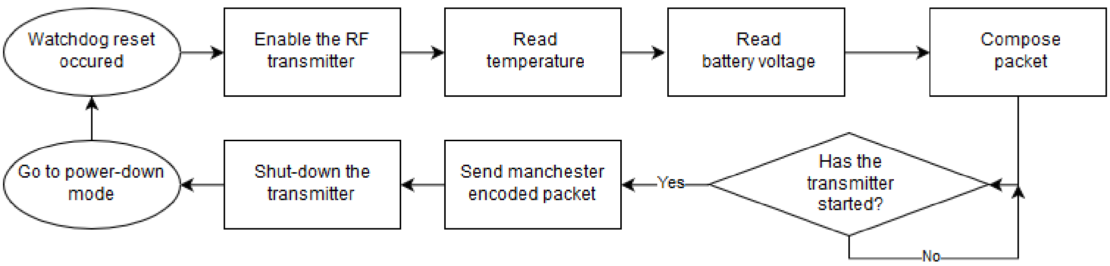


Figure 15: Transmitter software flow chart

After the MCU is started the Watchdog timer prescaler is programatically set to time-out after 1.0 seconds. This allows the MCU to enter power-down mode after completing transmitting to save power and be started again by the watchdog timer.
The transmitter is enabled by setting the ENABLE-pin high after which a timer is started to interrupt at 400us that designates the time it takes to start the crystal oscillator of the MICRF112 IC. Meanwhile the temperature reading and the battery voltage reading are taken and the packet is composed. When the timer interrupt occurs that indicates that the oscillator has started, the packet is sent by changing the output value of the ASK-pin at the nescessary bitrate.

Receiver design

The receiver is a smart-phone connectable peripheral with the ability to receive RF packets at 433.92MHz, decode it and forward the processed data through virtual COM port over USB.

Schematics & components

The circuit receives 5V from the USB-bus and the is protected by a resettable PTC fuse that is tripped at 1A. The USB connectivity to the smartphone is provided by FT234XD chip from FTDI. FT234XD is a compact USB serial to UART interface and provides a maxiumum of 50mA @ 3.3V from an integrated level-converter to the MICRF219A. The FT234XD is connected to the MCU ATTINY441 via UART interface without flow control.

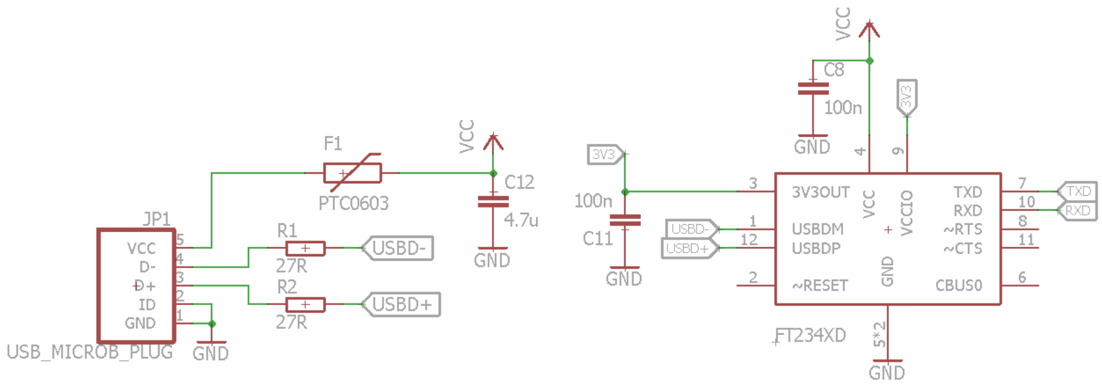


Figure 16: Receiver USB connectivity section design

The receiver uses Micrel MICRF219A RF receiver IC. The MICRF219A is 300MHz to 450MHz RF receiver with ASK/OOK demodulator with a data-out pin and

analog RSSI output [22]. The chip works at 3.0 to 3.6V and consumes 6mA of current while active [22]. The device supports bitrates up to 20kbps. The analogue RSSI pin outputs a voltage level corresponding to the strength of the incoming signal. The Data-out pin is for reading the demodulated data but is also used for programming the chip along with SCLK (programming clock) pin.
A crystal oscillator is required for the device operation that can be calculated by dividing the carrier frequency by 32,087 which gives us 13,52323MHz for the crystal value. This kind of crystal however was not available on market and a crystal with the frequency 13,52127MHz was used. The replacment crystal gives us the carrier frequency value of 433,86MHz. The 433.92MHz signal transmitter from the beacon can still be received and demodulated by the IC because is lies within IF-filter bandwidth of 330kHz.
C7 and L2 see on figure 17 are left for the possibility to tune the antenna to 50 ohms. Beacause the L1 and C6 components tune the input of the receiving chip to 50 ohms and the antenna used is already at 50 ohms C7 was replaced with a 0-ohm resistor and L2 was left unsoldered.

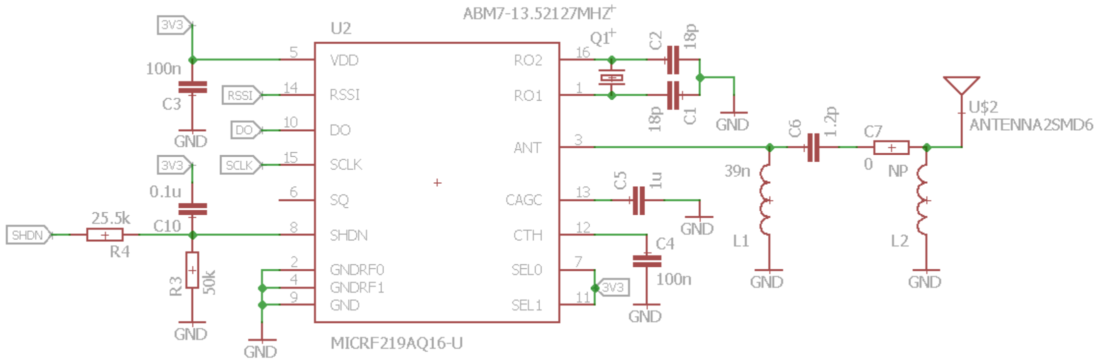


Figure 17: Receiver IC section design

Packet detection from the RF chip and packet forwarding to the smartphone through UART is managed by the Atmel 8-bit ATTINY441 MCU that works at 16MHz. The ATTINY441 is programmable by serial interface using the Atmel AVR MKII serial programmer and is also resettable by pressing the reset button.

The full schematic of the receiver is added in appendices.

PCB design

The PCB was designed so that it could be plugged into a micro-USB jack. The measurements of the PCB are 27x22mm and measurements with the USB plug are 36,8x22mm. The board thickness without components is 1 mm. For the given board thickness the RF trace width and clearance from GND plane was calculated to be 50 ohms according to coplanar waveguide calculation Equations (5) to (10). The PCB has the receiver MICRF219A, antenna and the reset button on the top side and ATTINY441 and FT234XD on the other side.

An image of the PCB design is added in the appendices.

Software

The main task of the MCU is to decode the received Manchester-encoded data from the demodulated data-out pin of the ASK receiver IC, check wheter the received data is valid, measure the RSSI while receiving the packet and eventually send the data through UART to the FTDI 234XD IC.

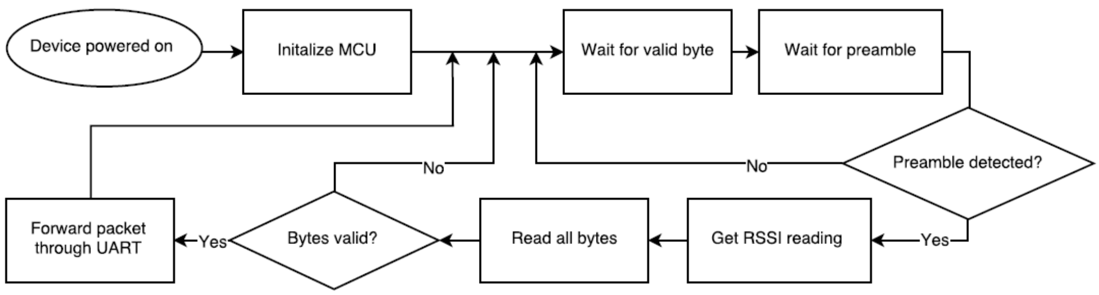


Figure 18: Receiver software flow chart

The decoding of the Manchester encoded data is timing-based and is realised by using the pin-change interrupts of the ATTINY. Every time the "data-out" pin value of the MICRF219A changes the timer value is saved in the pin-change interrupt routine. Meanwhile in the main program the consecutive timer values are interpreted and the real bit values are derived.
After the preamble is detected the RSSI-pin voltage measurement is taken using the ADC. When no errors occur while decoding the following 6-bytes, the received signature and payload data is validated using the according LRC value and is then sent through UART to the FT234XD.

USB connectivity

The USB OTG compatibility allows the smartphone to serve both as a host and slave. When a peripheral with the ID-pin grounded is connected to the smartphone, it automatically switches from slave mode into being a host device. In host mode the smartphone provides power to the USB-bus and enumerates connected peripherals.
The datalink between the receiver and an Android smartphone is made possible by the FTDI 234XD chip. The chip acts as an intermediate device as it provides a virtual COM port to the smartphone through which it can communicate with ATTINY441 MCU.
The chosen baudrate was 38400, with 1 stop-bit and no parity. Both the MCU UART interface and the virtual COM port in the Android application software must be configured with the same parameteres in order for the connection to work.

Android application

All the data received from beacons is forwarded through the USB virtual COM port to the application along with the RSSI reading. The application was developed using Android Studio and the minimum SDK version for this application is API 17 called Android 4.2 (Jelly Bean).
Application allows to add and delete individual transmitting beacons and has a visual and numeric indication of the signal strength. Battery voltage, temperature and approximate distance to the beacon is also displayed for each beacon.

Reading from the USB-port

The reading from the virtual COM-port provided by the FT234XD is realized using the library usbSerialForAndroid available at GitHub at url: `https://github.com/mik3y/usb-serial-for-android`.

When plugging in the receiver, UsbActivity is automatically launched if user has granted permanent permission to the app to access the receiver device. UsbActivity starts a Service called UsbService is started that tries to open the communication port with the FT234XD. If the port opened successfully, a Runnable is created (called the ReadingRunnable) that reads data from the UsbSerialPort of the device and forwards it to an extension of the Handler class called PacketHander. In PacketHandler class the raw data is processed, saved into a Bundle and sent as a Broadcast to the system. Also parameters like battery voltage and temperature are saved into the SQLite database of the application along with the current date and time.
The broadcasts can be received by registering a BroadcastListener and can be done so in any part of the application.

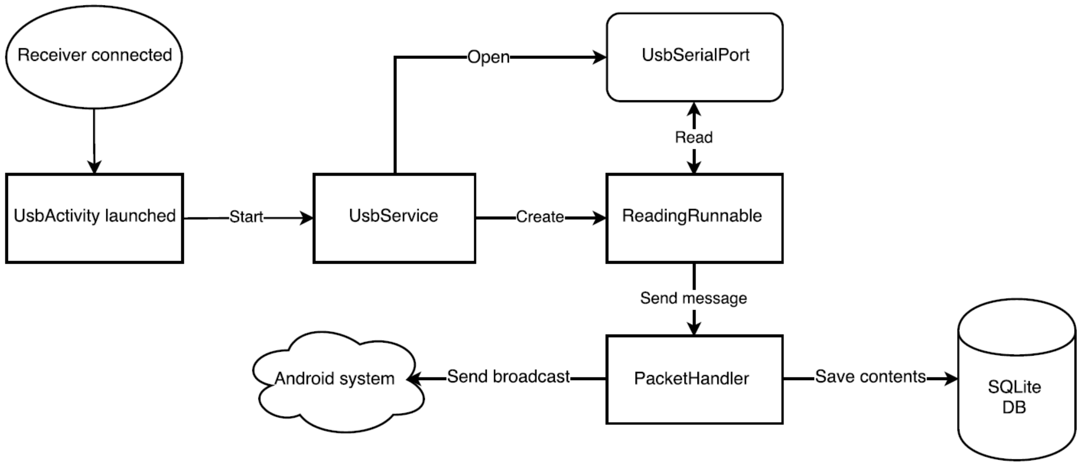
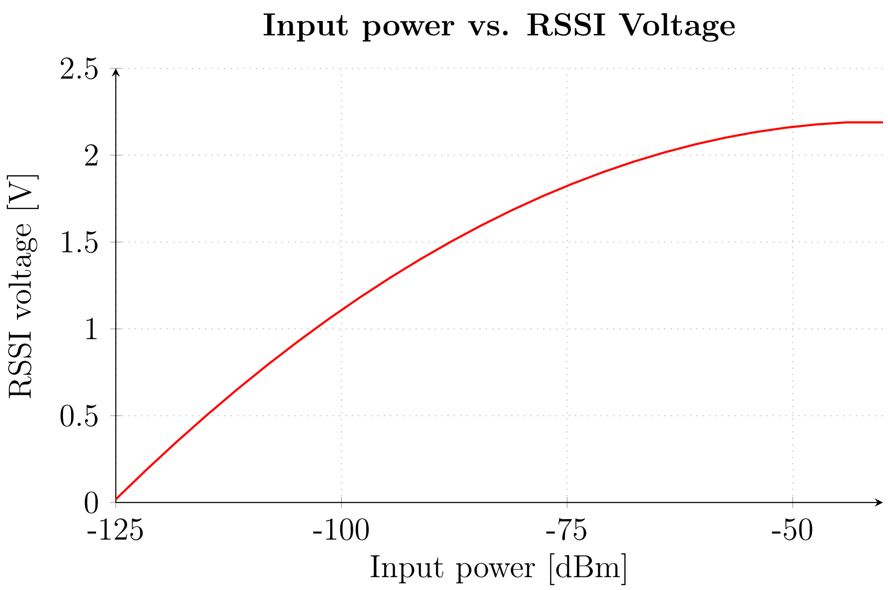


Figure 19: Reading from the USB virtual COM port

Calculating the signal strength

The signal strength in dBm is calculated in the application. The datasheet of the MICRF219A provides a graph which indicates the Input power vs. RSSI voltage.



To calculate the RSSI from the input voltage in range $V_{adc} = \{0; 2.1\}$ the following 3rd degree polynome was derived with curve fitting.

$$P = 18.3 * (V_{adc})^3 - 56.9 * (V_{adc})^2 + 78.3 * V_{adc} - 140.5$$

User interface

The application UI consists of 4 main activities:

Welcome screen
Displays a welcome message to the user on application launch.

Main screen
Displays a grid of beacons with their name, picture, battery level, last ping time and also a ping indicator.

Beacon screen
In addition to the data in the main view the beacon view displays a larger image of the beacon, large signal strength indicator, signal strength in dBm, battery voltage and temperature.

Adding a beacon
The beacon adding activity consist of multiple screens that guide the user through the process of searching for a new beacon and then assigning the beacon a name and an image, which the user can select either from the gallery or take a new picture using the camera.

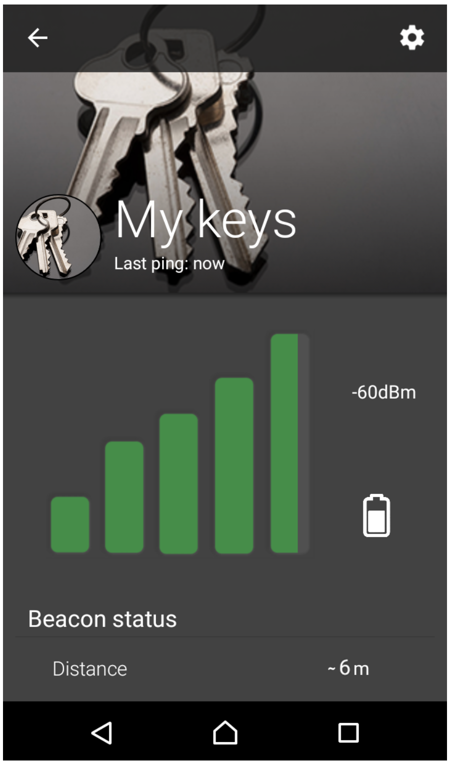


Figure 20: Screenshot of the beacon screen

Optimizing the RF circuits

The goal of the following measurements and calculation of components is to improve the performance of both the transmitter and receiver. All the measurements in this chapter were made using the **Hewlett Packard 4396A Network/Spectrum analyzer** with a 50-ohm RF probe soldered to the PCB in different configurations. The device was calibrated before the measurements using a calibration kit.

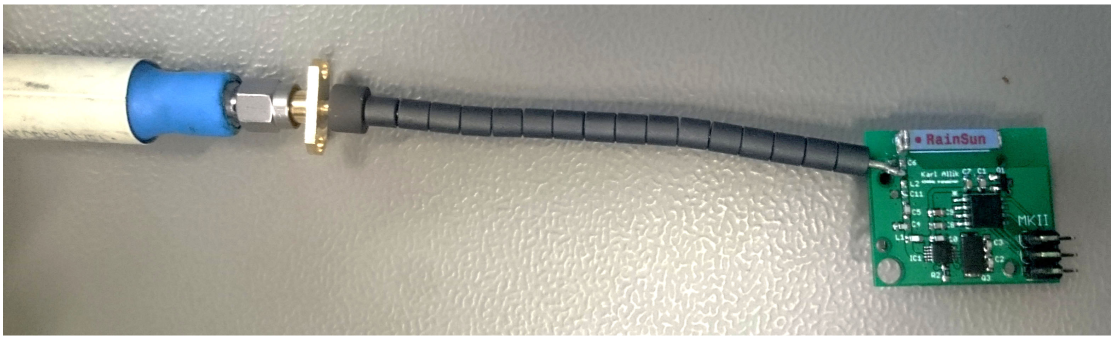


Figure 21: Measuring the VSWR of the receiver antenna

VSWR

For optimizing RF circuits it's important to understand the term voltage standing-wave-ratio. In an electrical transmission system, the SWR indicates how efficiently RF power transmits from the signal-power source, through the transmission line, into the load [29]. The SWR is the ratio between the transmitted and reflected waves and is referred also as the VSWR because it usually indicates the voltage ratio [29]. A higher VSWR indicates a poor transmission-line efficiency or a mismatched impedace. The amount of reflected power can be calculated with the following formulas: [27]

$$\Gamma = \frac{VSWR - 1}{VSWR + 1} \tag{14}$$

$$P_{ref}(\%) = 100 * \Gamma^2 \tag{15}$$

Transmitter

The transmitter RF network output must be matched to 50-ohms at 433.92 Mhz to ensure that the maximum amount of power is transferred to the antenna of the same impedance. Additionally adding a proper filter to the network can attenuate unwanted harmonics being transmitted.

The datasheet of the MICRF112 provides a schematic for the evaluation board with component values to tune the output of the IC to 50 ohms and to match the antenna to 50 ohms.

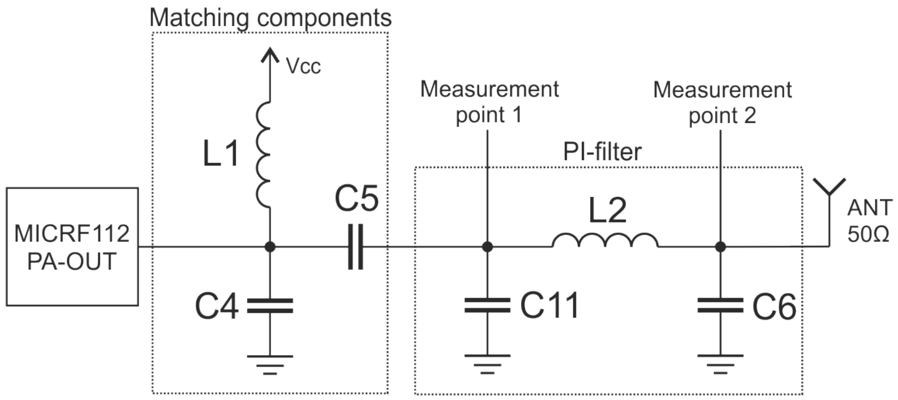


Figure 22: Measuring the VSWR of the receiver antenna

	L1	C4	C5	C11	L2	C6
Datasheet values	470nH	NP	10pF	NP	82nH	3,9pF
Used values	470nH	NP	27pF	18pF	11nH	18pF

The used antenna is already at 50-ohms so there was no need to do antenna matching, but only match the output of the MICRF112 to 50 ohms and attenuate unwanted harmonics so that they would not interfere with communications on other frequency bands.

Matching the output of MICRF112 to 50-ohms

Matching the output of the transmitting IC **MICRF112** to 50 ohms was done by measuring the signal strength with the **HP 4396A** in spectrum analyzer mode. The measurements were taken from the “Measurement point 1” with the PI-filter components removed.
Using the component values from datasheet application circuit the measured output was 5.01 dBm into the 50 ohm load provided by the analyzer. Out of the stated 10dBm output power of the MICRF112 the measured power is approximately 5dB lower than expected. By raising the value of C5 to 27pF we achieved 5,76 dBm into the 50-ohm load of the **HP 4396A**.

The achieved power level from the transmitter is a bit lower than half of the maximum output power of the MICRF112. This means that the matching was only partial and the output impedance isn't exactly 50 ohms, but the transmitter can still deliver 5,76dBm into a 50 ohm load.

	C5 equals 10pF	Changed C5 to 18pF	Changed C5 to 27pF
Measured signal strength (dBm)	5,01	5,6	5,76

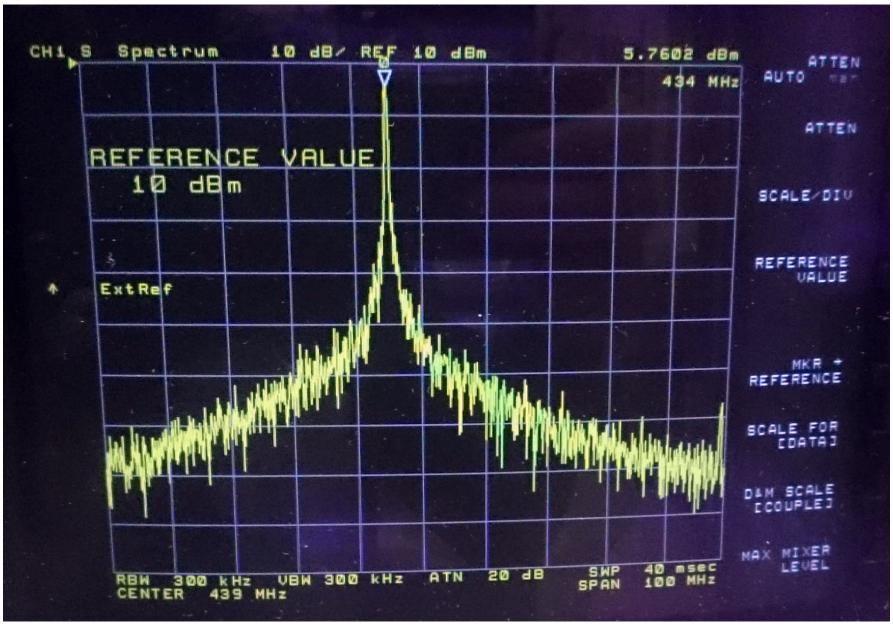


Figure 23: Output power of the MICRF112 with matching components

VSWR of the antenna

The VSWR of the RainSun AN1603-433 soldered to the PCB was measured from the "Measurement point 2" with the PI-filter components removed as can be seen on figure 22. The measured VSWR of the antenna at 433,92MHz was 1,62 and is lower than the maximum VSWR stated in the datasheet of the antenna.

Implementing the PI filter

For attenuating harmonics a 3 dB ripple Chebychev low-pass LC-filter or also known as the PI-filter was used. It is composed of C11, L2 and C6 using values calculated using Equations (11) to (13). The values were calculated with source and load resitance of 50-ohms and gave component values C11, C6 = 21pF and

L2 = 11nH.
The VSWR of the PI-filter was measured from the “Measurement point 1” with the matching components removed and the antenna attached to provide a 50-ohm load.
The measurements showed a VSWR of 2,34 at the frequency 433,92 MHz which means that the PI-filter decreases the power of the 433.92MHz signal transferred to the antenna.
Taking the parasitic capatacitances of the PCB into account, 21pF capacitors of the PI-filter were replaced with 18pF capacitors. The measurement was repeated and the resulting VSWR now was 1,52 ans based on Equations (14) to (15) this means that at least 95% of the power sent to the PI-filter is also transferred to the antenna.

Figure 24: S11 measurement of the PI-filter and the antenna

Receiver

The matching components L1 and C6 tune the input of the MICRF219A to 50 ohms and components C7 and L2 for matching the antenna to 50-ohms. The values of L1 and C6 were taken from the datasheet application circuit (L1 = 39nH, C6 = 1,9pF).
Because the impedance of the antenna is already 50-ohms, there is no need for the matching components, therefore the capacitor C7 was replaced with a 0 ohm resistor and L2 was removed.

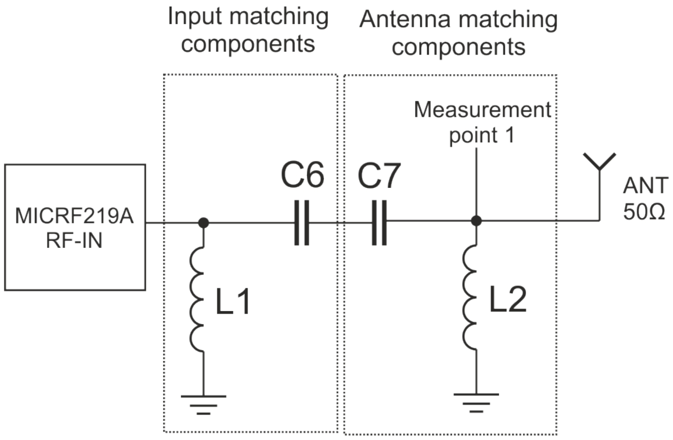


Figure 25: Receiver MCU section design

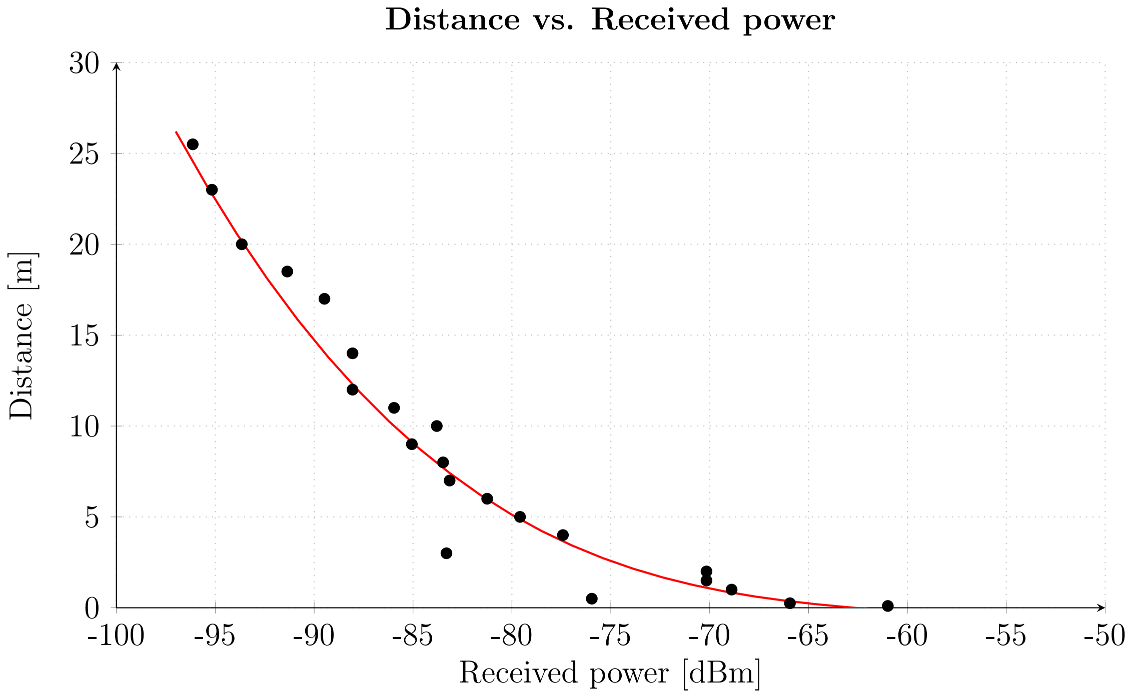
Position of the antenna

The following measurements were also made with the HP 4396A in S11 mode measuring VSWR from the Measurement point 1 with other components removed.
The initial measurement of the VSWR of the antenna at the system frequency gave the result of 2,3. Using Equations (14) to (15) we find that the antenna reflected back 15% of the power sent to it.
The distance of the antenna from the ground plane was initially 1,5mm, but by increasing the distance to 3,5mm the measured VSWR went down to 1,06, which means that almost no power was reflected back from the antenna.

Testing and results

Signal strength and working distance

The received signal strength tests were conducted outdoors in an open enviroment. The RSSI readings were taken from the receiver, which was attached to the smartphone.



The maximum range where the packets were continuously received was 25 meters where the approximate signal strength was -95dBm. When the receiver was 10cm from the device, the RSSI would rise up to -61dBm.
For comparison a 50-ohm quarter-wavelength whip antenna was attached to a second transmitter and the stable working range of that device was doubled at 50 meters.
Measuring the signal strength of the transmitter in a Faraday cage at Tartu Observatory showed a peak signal strength of **-20dBm** measured with a spectral analyzer connected to a large-scale UHF antenna.

To approximate the distance to the beacon using the signal strength in the range of $P_{dBm} = \{-100; -60\}$ the following 3rd degree polynome was derived using curve fitting:

$$Distance = -0.000461 * (P_{dBm})^3 - 0.083 * (P_{dBm})^2 + -5.06 * P_{dBm} - 104.73$$

Packet transmission

After testing different bitrates a stable performance was achieved at a maximum bitrate of **10 kbps** and because the data is manchester-encoded the real datarate is 5 kbps. At this datarate the packet loss was measured indoors at three different distances:

- At a distance of 1 meters (signal strength -69dBm) : 1 packet out of 100 was corrupted
- At a distance of 5 meters (signal strength -80dBm) : 42 packets out of 100 were corrupted
- At a distance of 20 meters (signal strength -93dBm) : 66 packets out of 100 were corrupted

As can be see from the test packet transmission works fairly stable when the signal strength is above -80dBm and is more affected by noise if the signal strength is lower than that.

Transmitter battery life

While not transmitting, the MICRF112 is in standby mode and the ATTINY25 is in power-down mode. In standby mode the MICRF112 consumes 1 uA of current [21] and the ATTINY25 consumes approximately 4 uA of current in the power-down mode with the watchdog timer active. This gives us the **standby current of 5uA**. While transmitting Manchester-encoded data the MICR112 draws 6.9mA [21] and the ATTINY25 draws approximately 2mA while working at 4MHz. This gives us the current consumption of **9mA while transmitting**. Using the system data-rate of 5kbps and the packet length we can calculate the sending time of a 8-byte packet, which equals about 12,8 ms and taking the oscillator start-up time of the MICRF112 into account, the **total on-time is 13,2ms**. As stated before, the watchdog timer restarts the MCU and turns on the transmitter after being in **power-down mode for 2 seconds**. By finding the average current consumption device we can estimate how long the device can work using a CR2032 battery. (CR2032 battery capacitance can be reduced from the nominal 240mAh to 175mAh when current is being drawn from it in pulses [8])

$$175mAh : \frac{0,005mA * 2sec + 9mA * 0,0132sec}{2sec + 0,0132sec} \approx 2735\ hours \approx 114\ days$$

The battery should last at least 114 days before the voltage becomes too low for the device to operate meaning that the inital requirement regarding the battery life of the transmitter was fulfilled.

Android application

The application was tested on two devices with USB OTG capabilies: Samsung Galaxy S3 running Android 4.3 and Sony Xperia Z3 Compact running Android 5.1.1 . The serial communication with the FT234XD and the application itself worked properly on both devices.

Usability

Overall the system worked properly and the transmitter could be found based on the RSSI. Moving from 50 cm to as near as 10 cm to the device, the RSSI level still rose and the accurate location of the transmitter could be detected.
However the RSSI readings would occasionally show unexpected values and fluctuate. This could be caused by the fact that the RSSI output of the receiver IC was analogue and had to be read with an ADC. Probably the system stablity could be raised by using a receiver with digital RSSI.
To make location objects even easier the system could be improved by changing from the transmitter and receiver scheme to a system with two transceivers. This way the beacon could notifiy the user about it's whereabouts by playing a sound or blinking an LED.

Conclusion

The main goal of this thesis was to design and complete a RF based system that would help the user to estimate the distance from the receiver to the transmitting beacon.
To understand the existing RF technologies, basic theory regarding RF modulation and antennas was presented. An overview of different existing RF technologies and their suitability for object tracking revealed that besides Bluetooth Low Energy there was no widely used alternative for finding objects based on RSSI.
For building such system an overview of RF modulation techniques, basic theory regarding antennas and different RF technologies proved useful for making the key decisions when building the system. A custom transmitter and receiver were designed using RF receiver and transmitter ICs from the company Micrel. The system was designed to use the frequency 433.92MHz using ASK modulation and the devices were built and programmed to support the exchange of the described packets.
The testing of the system showed a working range of up to 25 meters using the chip antennas and up to 50 meters when using a quarter-wavelength whip antenna for the transmitter. The developed transmitter beacon that would transmit a packet containing its signature, temperature and battery voltage after every two seconds. When transmitting an 8-byte packet at the given interval the beacon would theoretically work up to four months from a CR2032 battery.
Upon further optimizing the RF circuits the system could work at even longer ranges providing an alternative to Bluetooth Low Energy devices with a lower working range. To make location objects even easier and provide simlar functions as the BLE products, the system could be improved by changing from the transmitter and receiver setup to a system with two transceivers. This way the beacon could notifiy the user about it's whereabouts by playing a sound or blinking an LED.
Overall the concept of using RSSI for locating objects using a system composed of a small scale transmitter and a receiver proved to work as expected and the achieved range was in the same order of magnitude with the existing Bluetooth Low Energy systems.

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Appendices

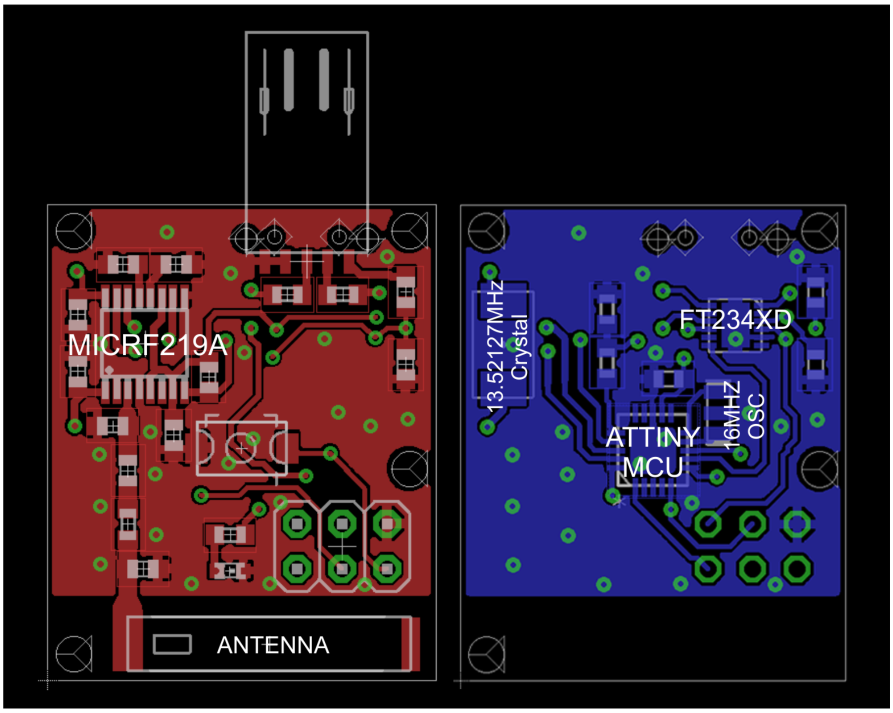

Figure 26: Receiver PCB top and bottom design

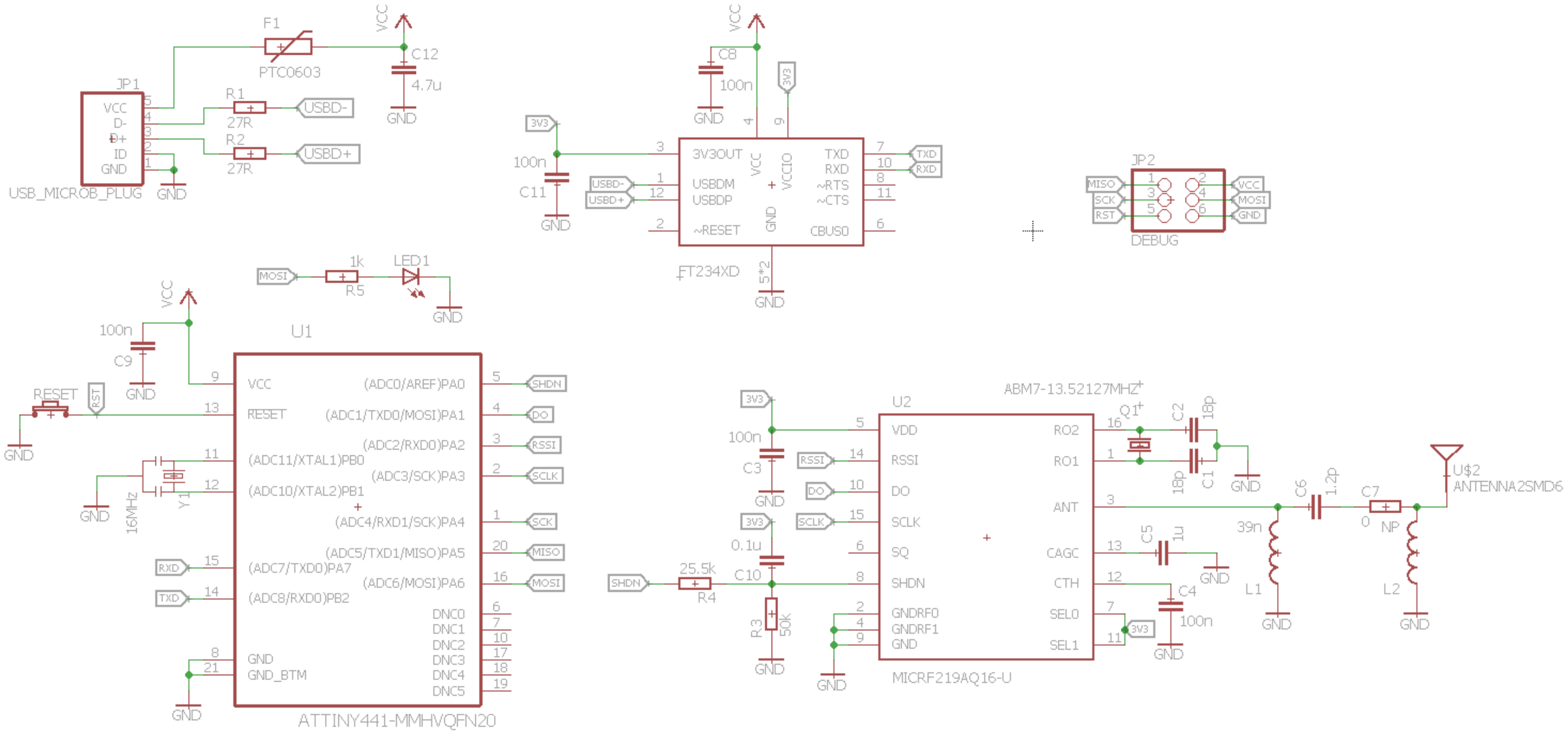

Figure 27: Receiver full schematic

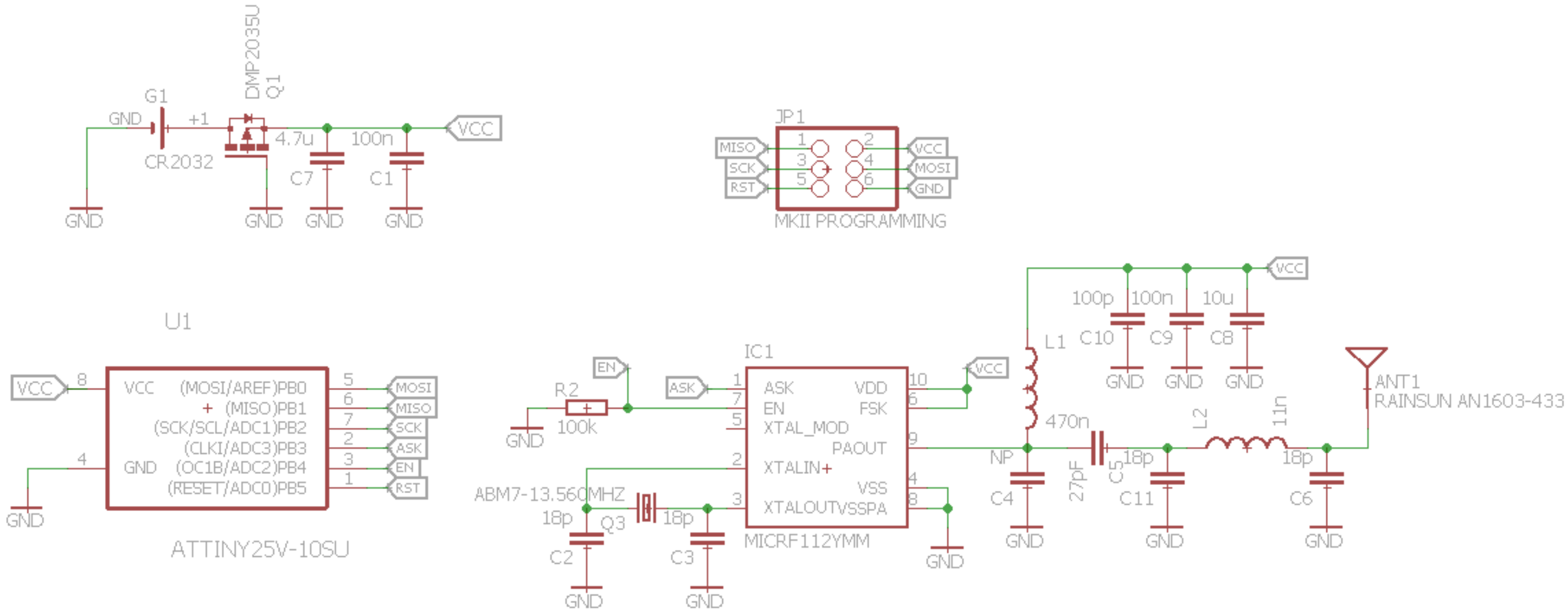

Figure 28: Transmitter full schematic

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