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RFID MODULE FOR A MEDICAL AUTOMATION ROBOT

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ABSTRACT

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The objective of this Master’s thesis was to design a RFID reader module for a medical automation robot. The task was commissioned by Ginolis Oy. The topic of the thesis came from the company. The idea was to create a device that can be integrated in all of the company's current and future robotic devices. Future plans need to be taken into account too. An RFID reader should work in a way that there is a possibility to integrate it in the future, for example in a manually operated portable device.

Before the implementation phase it was necessary to find out information about the topic that was not familiar to me it included the recognition of advantages and disadvantages of different RFID technologies, and their suitability for the company’s use. This meant in practice that work started with requirements definitions. Making this definition turned out challenging as the company itself did not have clear requirements for the reader. One challenge was that the actual integration in the design was still in progress. The result of all this was that the plans changed and lived constantly during the design and definition process.

Hardware and the software did not exist. All needed to be custom built from the blank to suit the company’s needs. In the hardware design phase, I needed to create a few versions, due to the implementation of the antenna.

The fully functional RFID reader would be a beneficial device for the Ginolis. As a whole, after all work and studies, the final version of the RFID module was a success. Ginolis got the reader that they requested. The reading distance was a little disappointment but it is something that can be fixed in the future.

Keywords: NFC, RFID, Tag, HF, LF, UHF, User recognition, asset tracking

PREFACE

The work was comissioned by Ginolis Ltd. The company provided the working environment and some external support to accomplish the thesis. The work took place mostly at home through the writing process.

From Ginolis, the supervisor for the thesis was Ilkka Sormunen, Director of software development, and as an advisor for work was Jarmo Paloviita, Manager of robot applications. Together we shared some interesting discussions about the technology of the RFID module. Hannu Viitalähde from Ginolis was involved in the thesis from the beginning. He supervised and oversaw the PCB designing phase of the RFID module. The code was mostly written by him.

Oulu, 8.12.2015
Mikko Mikkonen

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VOCABULARY

NFC	Near Field Communication. Radio communication for a short distance.
IC	Integrated Circuit.
EMC	Electromagnetic Compatibility. A Measurement of electromagnetic interference.
Q-Value	Indicates the relative energy loss of transmit power caused by the damping materials.
CAN Bus	Controller Area Network. A Vehicle and industrial standard. A Method of microcontroller and device communication.
I2C	Inter Integrated Circuit. A Multi-master, multi-slave, single-ended, serial computer bus.
SPI	Serial Peripheral Interface. Short distance communication in embedded systems.
PCB	Printed Circuit Board.
TVDD	Total Voltage Drain Drain
TX1	Serial Communication Transmitter. Usually connects to RX, Serial Communication Receiver.
P2P	Peer-to-Peer. A Network where nodes share resources.
WORM	Write Once, Read Many.
EIRP	Equivalent Isotopically Radiated Power.

1 INTRODUCTION

Ginolis is a company which provides manufacturing solutions, dispensing pump solutions, contract development and manufacturing services for products of high precision in-vitro (IVD) diagnostic disposables [5].

The aim of this thesis was to find out and design the best possible RFID reader module solution for a Delilah robot. Delilah is the name of a medical automation robot to which RFID reader was to be made. The aim of this work was to compare different kinds of solutions between different models of RFID/NFC integrated in circuits and technologies. The main challenges of this work were to find out the right frequency which would be the most suitable in this case. Also, the aim was to find the right antenna technology that can be adaptive for different kinds of mounting places for the future projects. The whole vision of the implementation was not clear from the Ginolis point of view which set a challenge to make something that would be flexible enough for their future projects.

After the right IC and antenna technology had been chosen, also the right kind of tag for this robotic project needed be chosen. The tag can be used as a final “tuning” component for having the right distance between the transmitter and receiver. This feature will be handy in the future developments because it is possible to use a large variation of different kinds of tags with this RFID module.

For finding the right technology, it was important to get familiar with the world of RFID by using some test kits.

2 MEDICAL AUTOMATION ROBOT DELILAH

The RFID reader was designed to be implemented in any product of the company. It was mainly designed for the Delilah robot. Delilah is a sample processing robot unit as shown in the figure 1. The purpose of this kind of technology can be found in various places in medical field. Delilah works mostly by moving samples in petri dishes or test tubes. This handling and moving process is sometimes hard to follow, therefore the RFID reader is needed. It keeps track of the location and phase of the samples which it is going to or has gone through. The cassette that needed to be tracked goes from the left magnetic table to the table on the right as shown in the figure 1.

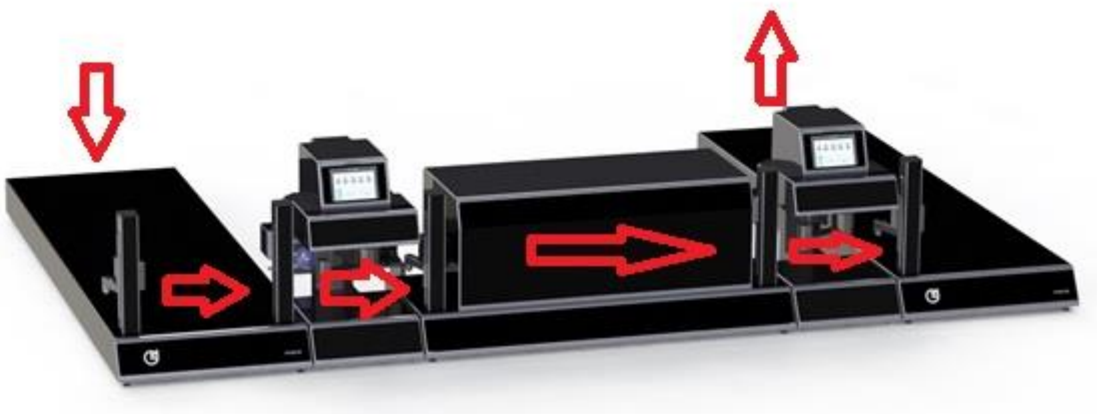

FIGURE 1. Sample processing system, including Delilah.

3 REQUIREMENTS

The definition for the RFID reader module comes mostly from the company. The module evolved so that some features and attributes came from environmental reasons. This means that there were some unknown factors also from the company, and they where needed to be resolved. Unknown factors were mechanical design issues of the complete sample the processing system.

The RFID module should be fitted in various places in Ginolis's future projects. Some features were introduced for a future use only. One of these features was the idea to use the module as an RFID writer. Also the shape and the design should be easily implemented in a hand held device for a future use.

3.1 RFID size, placement and mounting

The RFID Module needs to be fitted behind the glass screen of the Delilah robot. There are specific measurements for the fitting of the PCB of the module under the glass. There is also a logo that glows under the glass as shown in figures 2 and 3. This logo area should be the area where the reading/writing of the tags should happen.

FIGURE 2. Delilah, Controlboard.

FIGURE 3. Delilah.

Figure 4 depicts a magnetic sled where the module must fit. A sled moves with the RFID module in the whole table area in a longitudinal lateral movement as seen in figure4. The antenna and the readers electronic should be both located in the sled. This is because the CAN bus goes to the sled and the RFID module should be attached to the nearest CAN bus access point. All the extra wires need to be avoided. Working under the glass table is something that had to be tested and studied. The glass is normal, no lead or iron included, and the thickness will be 6mm. The only extra material on the glass is the epoxy based paint cover.

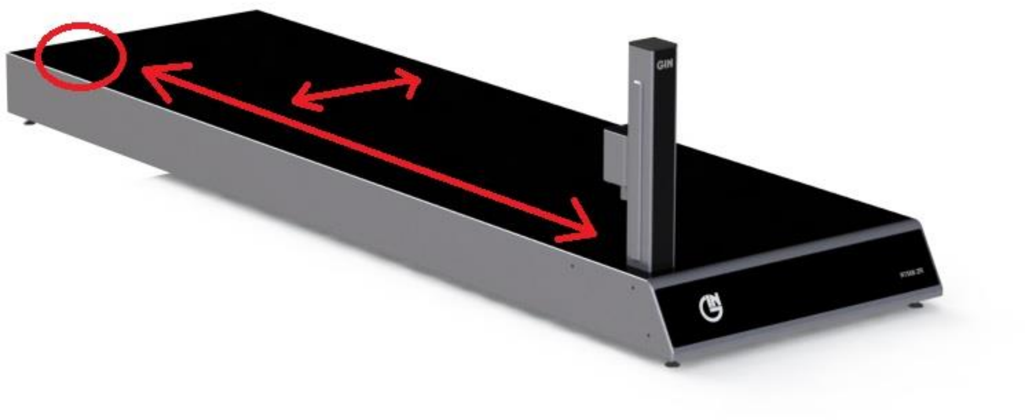

FIGURE 4. Magnetic table. Cassette moving directions.

The original design of the cassette had two tags in each. One at the side and one at the bottom as seen in the figure 5. The side one is for tracking the cassettes movements through the process. The one at the bottom is for the magnetic table. With this the system knows which cassette to pick or which cassette has been picked. This happens at the beginning and at the end of the whole process.

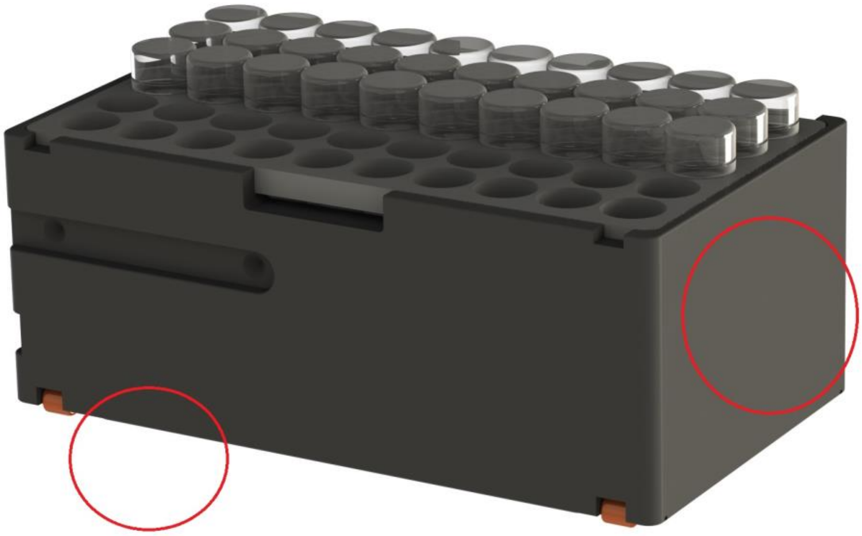

FIGURE 5. Sample transport cassette.

As the module needed to be expandable by its features, I chose a fairly common PN532 controller for the RFID. It already had the flexibility for more than it was needed to complete this thesis. More functions may be added in the future projects.

Ginolis also needed to have the option for writing the RFID chips and the PN532 suited this intension nicely. From my point of view the need for writing would be mainly for giving access rights for the user’s tags.

The first place for the implementation was under the glass table in a motorized tray. Some new location for the implementation came along later.

The connection on the main board was through a CAN bus. Ginolis hoped that tit would be possible to insert the RFID module in the molex connectors of the mainboard between the led lights as shown in the figures 2 and 3.

From the physical point of view, it was obvious that the RFID module should be small and as durable as possible. It will be in multiple locations from non-moving platforms to hand held devices. Theresome, it will need to endure some vibration and slamming.

Later there came some new definitions for the RFID module. Ginolis wanted to attach the reader also to the manipulator, which moves the tip holders in stacks as shown in the figure 6. The reason for this was that the company changed the design of the cassette so that there are now two separate components in each cassette, a tip holder and the cassette. The cassette moves on the magnetic table and still has that one tag at the bottom. Now the tip holders are in a separate tray which can be stacked multiple units on the cassette. Each tip holder has its own tag for identification at the side of the holder tray.

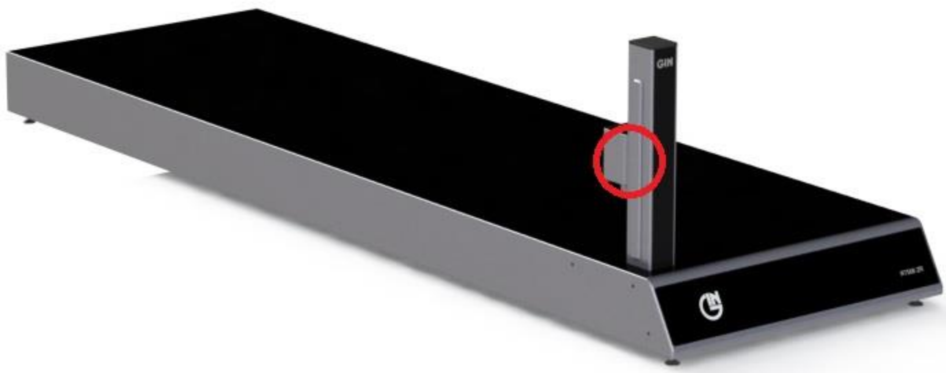

FIGURE 6. Magnetic table. RFID module atachement location for pole grabber.

The complete system, where the RFID module is implemented could look something like in the next picture. A complete system consists of different modules, each of them having its specific needs. This enables to build a desired process line to meet every customer's needs. The RFID module is one of the key features in this system. It gives information about what sample left from the first table, what happened in the middle phases and when it is at the end of the process line as shown in the Figure 7. The user can more easily know which cassette is transporting and which samples are transported and where.

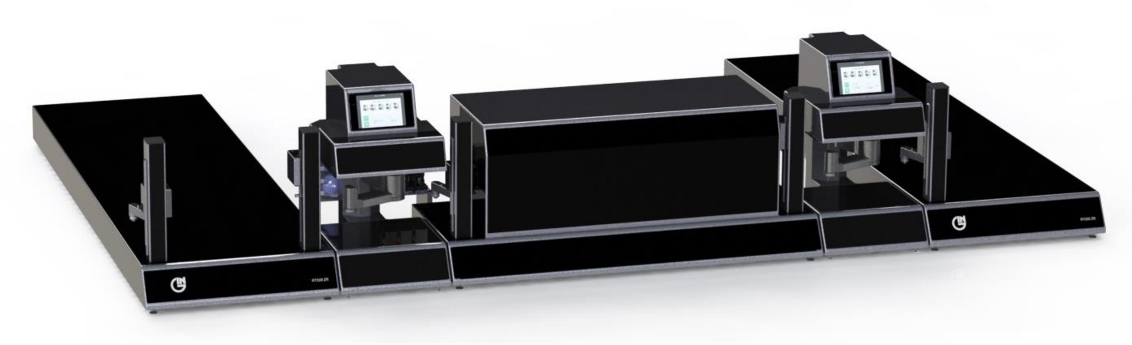

FIGURE 7. Sample processing system.

When choosing the tag, it was important that it were alcohol resistant because it would go through disinfection process.

One of the new features was that it would be possible to mount the RFID reader to the Delilah's cassette moving hand as seen in the figure 6 and 7.

During finding the right requirements for designing the RFID module, the cassette design changed. In the new design there will be only one tag in each cassette. The tag goes in the shuttle which moves cassette stacks.

3.1.1 RFID-signal strength requirements

In the environment factor there where some main variables that needed to be taken into account when finding the right solution for the implementation.

The glass on the cassette moving table. The RFID module will be under the glass inside the table. The module will be moving with the mechanics that will be moving the cassettes on the table. The tag is needed to read through the glass. There was not any absolute information available about what will be the thickness of the glass. This was not a problem because I got an information that the thickness will be something between 4mm-8mm. This 4mm range can make a huge difference in the Q-value of the RFID signal.

The control boards in these robots are located mainly inside the metal frames. It was necessary to make sure that the RFID signal will not need to go through a metal frame or grid. This obstacle would block the signal completely.

During the designing of Delilah's parts, I found out that the RFID module will be located in some cases inside a plastic cover. You needed to ensure that the material of the plastic will not include any materials that will block the RFID signal. One of these compounds could be, for example lead.

3.1.2 PCB size and placement requirements

Physical requirements were hard to define in the very beginning. It was not completely clear what will be fitted in the same PCB with all the RFID components. Mainly, all the designs needed to be complete before a certain phase of the designing process of Delilah. The reason for this was that they could make a right kind of slot for the RFID module for implementation.

At the magnetic shuttle the only restriction was that the width of RFID module cannot be over 60mm.

At the front panel of Delilah shown in the figure 2 and 3 the size of the PCB can be only 40mm x 40mm, it should be as slim as possible. This size is really hard to achieve without making some special modification in the PCB and leaving PIC32 off from the design.

The cassette lifting hand came in the picture in the later phase of the design. There were no specific requirements for this, until at the end when closing the final design of the PCB Ginolis wanted to know all the physical attributes of the RFID module, so that they can modify the lifting hand for the module.

Antennas were a big issue in this thesis. There was a huge amount of questions about this topic. I was forced to skip mostly the designing phase of an antenna, because making an antenna for this RFID module would be a completely own thesis. My intension was that I would use some already existing schematics from some open hardware project, and implement it to this project. In this case it meant that the antenna design will be close to the design of the kit that I choose for testing the functionality of the PN532 IC.

The antenna location and size will be 60mm x 47mm and 4mm of thickness. The antenna will circle the PCB. RFID IC should be located close to the middle of the PCB. This way it would take the least amount of distortion from the antenna. This kind of antenna will build some inductance in the surrounding area. The inductance of this kind of coil antenna will be in the area of microhenry, thus the effect to the RFID IC will be close to nothing when the antenna and the IC are not located one on top of the other.

Physical restrictions are divided into two groups. The reason for this is that when the designing of this module started, we did not know all the possible features and restrictions of the RFID reader/writer and the Delilah robot where the module was supposed to be attached. The first part describes the limitations of the table at the beginning. The second part describes the restrictions that came in when designing the final product.

At first the size of the reader could be maximum 40mm x 40mm. This was the limitation in the mainboards connection slot it was designed so that it could added to this module in the future. This area is surrounded by led lights, so it is not possible to have any bigger PCB assembled in that slot, or it will block the lights. The physical connection between the module and the mainboard happens between two Molex connectors, which that are 30mm away from each [3]. In this first idea of the design it was also planned that the PCB of the module should have been designed so that the actual PIC32 controller would be in the same board with the RFID circuit. The amount of layers in the PCB would have been between 4 and 6.

Some features that came in later when doing the design. One of these features was to be able to attach the RFID module to a pole grabber. The pole grabber was an ideological design at that time. Ginolis had a theory that the pole grabber is a vertical moving part of the bigger unit that gives some restrictions for the RFID modules cording.

Some physical restrictions that where valid during the whole design process. A magnetic glass table was the first unit where the RFID module where supposed to be implemented. In this unit the most important restriction was that the RFID module cannot have a reading distance of more than 5cm. The reason for this was that the magnetic table will hold multiple pieces of cassettes which will each hold one tag and there cannot be a possibility that the RFID module will mix cassettes tag signals.

3.2 Design versatility requirements

The most important feature for this RFID module is the reading of different kinds of RFID and NFC tags. My personal challenge in this was to find a radio microchip which would be the most flexible with many different kinds of tag types, it should also be supported in the future as far as possible with new tag types. This was a one reason why the PN532 was chosen to this work. The other reason is that the PN532 is so extremely easy to upgrade for the future models.

Writing should be supported but it is not needed as a function in the first model. This option should be just included in the RFID IC.

User recognition is included in the reading function but it was a requirement as a feature from the company. This mostly has some effect when choosing the tag. A tag needs to be able to carry enough data about the user.

Reading speed was a factor that will be important when Delilah is fully finished and operational, i.e. how much time there is to spend for reading the data from each tag. The problem is that the wanted speed is still an unknown factor. The estimation is that it should read at the speed of one second per tag.

3.2.1 Portability

This feature is mostly for the future development. There is an idea that this RFID module could be implemented in a handheld device which has not yet been designed. In this case it is important to have flexibility to affect the reading distance by swapping the size of the antenna from the PCB and/or using different tags.

3.2.2 Modularity

Because of the environmental factions the antenna will be a separate part in this design. This will give some nice flexibility in the use of this module. Now, the module can be attached to the wanted mounting place so that the electronic will be close to the mainboard of the robot and the reading and writing antenna unit can be located in the place where it is the easiest to use for tags and users.

3.3 Operation

The CAN Bus communication is 8 bytes in one direction. The first byte is the command, second byte is the writing. The Last 7 bytes are in free use. This was the most important and the only requirement from Ginolis at the beginning of the thesis. Mainly, this will effect when choosing the right RFID IC for the PIC32. And in this case there where two options. The first one is to integrate the RFID IC and PIC32 in the same PCB and transfer the data in and out by using CAN Bus. The second option is to have a separate PCB for the RFID IC and for the PIC32.

Using this RFID module for the user recognition and controlling the different user levels is an important feature which will mostly be handled by an external device example tablet. The role of the RFID module is only to support the tag type and give the possibility to write user tags.

Asset tracking in the production line is the main feature. The asset in this case is the cassette that includes medical samples. The asset will be read in the beginning of the production line. This way it will be possible to track the asset through the process.

A possibility to write something in the asset tags enables to have an acknowledgement for the products. This way we can know is the asset went through some specific phase and where it is going.

3.4 RF frequency and transmit power requirements and restrictions

In here some of the basic restrictions about the standards and regulations according to RFID and NFC devices are explained. This is crucial information which was taken into account when developing the RFID reader/writer for Ginolis. From the many frequency options the chosen frequency range of 13.553 MHz to 13.567 MHz Bandwidth 14 kHz, Center frequency 13.560 MHz is available Worldwide.

It is important that you know which countries you can operate in (legal restrictions). Every country has its own radio regulations. They help to minimize radio chaos. It is not possible that anyone could use any radio frequency that they would like for any purpose. The interference would make the whole radio system unusable. It would be great if the regulations were the same in every country. Unfortunately, radio regulations do not extend seamlessly between countries at the moment. This situation is improving all the time. In future it could have an effect on what type of RFID system you are allowed to use.
You can operate RFID devices in the ISM bands (Industrial, Scientific and Medical). In the ISM bands you will not need a radio license, but you will share this band with other services. The regulations specify which frequencies are used for ISM and which RFID frequencies can be used within them. The International Telecommunication Union (ITU) has set some international standards to ensure that frequency bands are used sensibly. The ITU has designated a number of bands that countries can use for ISM. Each country decides what frequencies to

use within the ISM bands and most countries have various services already operating in the ISM bands on established frequencies.
There are some specific RFID frequencies, especially those frequencies which are used for more critical operations, thus they cannot be interfered with.
It is limited the transmit power that can be used. The reason for this is that if anyone could use as much power as they wanted, it would be possible to read tags over a very large distance, but the interference would affect to other services. A point focused RF transmission from far distances might overpower a weaker local RF signal.

RFID products must comply with the standards mandated by each country. These are handled closer in the next chapter. RFID equipment suppliers should ensure that the RFID products do comply.

A radio regulation sets legal limits. This includes placing an upper limit on the power that a reader or an active tag is allowed to transmit. Radio regulations limit the transmit power. For example, the regulations in the USA limit the transmit power to 4Watts EIRP (Equivalent Isotopically Radiated Power) in the UHF band. This limit helps preventing interference that might occur if you transmit a very intense beam of radio energy from a highly directional high-gain antenna. In more specific look this means that 4 Watts is the maximum power (the amount of energy per every second) that you are allowed to radiate out of your antenna. This is different to the power you put into the antenna. If the antenna radiates in all directions, you could put 4 Watts into it and the EIRP would be 4 Watts out. But if the antenna focuses all this energy into a beam that has e.g. 10x the intensity that it would otherwise have, then if you put 4 Watts into the antenna you would be radiating 4x10 = 40 Watts EIRP out of it and be violating the regulation in the direction the antenna is pointing at.

The distance over which you can read RFID tags, depends not only on frequency but, on several other things too. The manufacturer’s specification for the read range of any specific RFID device should be clear before anyone should be thinking of using it. RFID frequencies affect the maximum distance over which you can read a tag, and affects the amount of power that can be transferred from the reader. This is important if the tag does not have a battery and if it is relying on radiated energy from the reader to power its microchip. Applications where a tag and a reader can work naturally, or be arranged to come into close contact, usually use LF RFID frequencies. The influence of the LF RF field falls off quite fast as the distance between the card and the reader is increases and the usable range is limited to perhaps a few centimeters. In general, the higher the frequency, the greater is the range. This is because RF radiation has more energy at higher frequencies. Higher frequencies can also bring their own complications. At higher frequencies the RF can be more easily obstructed or absorbed by objects in and around the line of sight between the reader and the tags.

When you read an RFID tag, data is transferred between the tag and the reader. RFID frequencies affect the maximum transfer speed. A higher frequency means that it’s possible to read tags faster. If you have hundreds of tags to be read and if the tags are moving, this can be very important. It is not possible to read multiple tags at the same time by using only one reader. Tags are read one by one, but the time it takes to read an RFID tag is so short that it appears to be simultaneous.
An RFID has a chip and an antenna. These are mounted on some kind of structure, e.g. a card or keying. The size of the tag mostly depends on the size of the antenna. The tag has to be at least as large as its antenna. The lower the frequency, the larger the antenna has to be. So LF tags tend to be larger than the ones that operate at the higher RFID frequencies. In some cases tags size does not matter. If the object to which you want to attach the tag is large enough to take a larger tag, then you can capitalize on any advantages that LF has to offer for your application.

RF energy at the higher RFID frequencies tends to be absorbed more by water than energy at the lower frequencies. This affects mostly when identifying food products, containing water, which are moving along a conveyor. It would be more recommended to use equipment that uses the lower RFID frequencies, while considering the LF's limitations of short range and slow speed. The higher RFID frequencies are affected more by conducting materials (especially metal objects) that are nearby. These can reflect, reduce or totally block the RF signal. LF RFID frequencies are far less susceptible to nearby conducting materials as the signals can often go around them.

3.4.1 Standards

Standards and regulations are one of the key features when building a radio device. By complying these regulations to the project, it is possible to make it to pass the Electromagnetic Compatibility EMC measurements.

The regulations in the USA limit the transmit power in the UHF band to 4Watts.

ETSI (European Telecommunication Standards Institute) produces globally applicable standards for ICT (Information and Communication Technologies), including fixed, mobile, radio, converged, broadcast and Internet technologies.

EPC (Electronic Product Code is a universal identifier which provides a unique identify for every physical object anywhere in the world. EPCs are not designed exclusively for use with RFID data carriers. The EPC is designed to meet the needs of various industries, while guaranteeing uniqueness for all EPC-compliant tags [1].

ISO/IEC standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.

ISO International Standards ensure that products and services are safe, reliable and of good quality. For business, they are strategic tools that reduce costs by minimizing waste and errors, and increasing productivity. They help companies to access new markets, level the playing field for developing countries and facilitate free and fair global trade. ISO/IEC 14443: This standard is a popular HF (13.56 MHz) standard for HighFIDs which is being used as the basis of RFID-enabled passports under ICAO 9303. The Near Field Communication standard that lets mobile devices act as RFID readers/transponders is also based on ISO/IEC 14443. ISO/IEC 15693: This is also a popular HF (13.56 MHz) standard for HighFIDs widely used for non-contact smart payment and credit cards [2].

In this work Mifare Classic and Ultralight tags are used and the standard for these tags is 14443-3 Type A [3].

ISO/IEC 18000-3: is an international standard for the passive RFID item level identification and describes the parameters for air interface communications at 13,56 MHz [4].

By going through the standards and finding the country limitations, it was possible to find out the best possible tag type for this work. Influence of these where not only restricted to the choosing the right tag type, but also to the antenna technology. The reason for going through all this was that the Ginolis wanted to have a globally approved product so that it would be approved in the near future in all of their products, no matter in which country they would sell the robots.

From all of this, the conclusion was that the chosen radio frequency and the transmit power of the PN532 are suitable in this design.

4 SELECTING THE TECHNOLOGY

In this chapter the grounds for selecting the components for the RFID module are presented e.g., selecting the IC, antenna type and frequency and the tag.

Consultation was a crucial part in the work process. It was interesting to find out the opinions of RFID module design and realize that building something like this is not so unequivocal thing. There were some things that consultants did not see in the same way.

A comparison between two technologies, NFC and RFID, needed to be done to determine the right technology for the use of Delilah.

In NFC we have the possibility to have also read and write capability. NFC devices can read passive tags and some devices are able to read HF RFID tags that are compliant with ISO 15693. NFC has a two-way communication, card emulation and P2P capabilities. The mostly used frequency is 13,56MHz.

RFID has the read and write capability but most of the solutions are made by using read only because of the simplicity. Some tags in RFID are only WORM type. It has a wider range of frequencies that have been used. The broadcast frequency 850 to 900 MHz, LF 125-134 kHz, HF 13.56 MHz, UHF 856-960 MHz. It has a longer reading distance than NFC: Active and Semi-passive about 30-metre distance, about 6-metre distance passive.

Both technologies have some same features including the RW function, 13,56 MHz and they use same tag types. Thus, the selected technology is based on the frequency that is most used and supported.

Ease in prototyping made the designing easier. In this case Arduino had exactly the same RFID chip in one of their shields.

Because the RFID range was a key feature transmit power, the restrictions of it in the use of the RFID chip were a crucial factor. Active tags have a battery or a external power supply, allowing them to transmit UP to the maximum legal power limit. A passive tag does not have the battery. It takes the power from somewhere else and shortens the distance. The tag captures some of the RF energy. The higher transmit power means a greater RFID range. High power areas can be problematic especially in medical areas. Each country puts a limit on the transmit power that a reader or tag is legally allowed to transmit, and this is enforced by law. Without these limits, a radio system would be chaotic and unworkable. It is possible to operate RFID without a license in the ISM bands (Industrial, Scientific and Medical). With passive tags the amount of power that the tag needs to get from the reader to enable it to operate is important. A passive tag is usually simple and does not draw a lot of energy from the reader's RF field to operate. Yet with active tags it is possible to operate a much greater range than with passive tags. They do not need to draw the energy from the reader, but usually they get the power from theyr internal battery. Some manufacturer's battery life has claimed to be up to five years [10].

4.1 Components

When choosing the right IC for the RFID module, it is crucial to find out some information about different component manufacturer. It is important to know the reliability of the manufacturer when thinking of getting the support and supply of the component in the future. Obviously, one thing that needs to be compared between different manufacturers is the prize of the component.

For this work, the right manufacturer was NXP Semiconductors. This company was proven to be reliable to produce the PN532 now and in the future. Their version of the IC was so universal in design that if the unfortunate will happen and the NXP will not be able to produce these components anymore, there will be other companies with a suitable version of the PN532. NXP was also the only company that provided support through email query. They even gave the contact information of their local regional distributor for getting the Finnish support [12].

4.1.1 IC

When comparing the different possibilities of the RFID solution, it was not clear what kinds of features where necessary for the future use. The best solution for this problem was to have something that was a familiar product with a lot of extra features. The definition of the familiarity of some component or product is that it is well known in tinker society and in the company.

Ginolis gave me the possibility to choose the way how the RFID IC will connect to the PIC32. PN532 had the options of I2C, SPI and HUART. From these I chose SPI. The reason to use this was that it was faster than HUART and not so familiar than I2C. SPI gave the chance to learn something new [9].

4.1.2 Antenna

An antenna transmits to the inductor direction. This gives the more accurate alignment of the transmission between the RFID module and the tag.

The antenna was a separate component in the first design. In the next design it was added to the same PCB with all the other components, but it was still a separate schema that could easily be modified for a desired size and transmit distance. When having no experience of antenna designing, it was nice to find out that the final fine tuning can be done by choosing the tag. The induction properties of the tag affect the whole transmit distance of the RFID system.

Both a reader and a tag have an antenna. To enable data communications, each of them must be able to receive some of the transmitted RF energy from the other so that the information can be recovered, from the RF carrier, and used. A simple whip antenna radiates RF energy in most directions, similar to the way a light bulb radiates light energy in most directions. In this RFID case the antenna radiates more directly. Some types of antenna focus the radiation into a beam. By sending the energy only toward the tags, there comes no waste of any energy. When sending it in directions where there are no tags, it is possible to increase the RFID range. The more directors an antenna has, the narrower, or more focused, is the beam. But the narrower the beam, the more accurately it needs to be aimed at, as the target area is smaller and the tags have to be closer together. But it is not possible to just add a highly directional antenna to a RFID reader and focus all your power into a narrow beam to increase the RFID range. Any other radio receiver within the influence of this concentrated beam might also be adversely influenced. An intensely focused RF transmission from far away might overpower a weaker local RF signal. Transmit power needs to be limited from the antenna and this depends on the type of the used antenna. The regulations in the USA limit the transmit power in the UHF band to 4Watts EIRP. EIRP is the Effective Isotropic Radiated Power and is the amount of focused power (the beam) transmitted from a directional antenna. This power is simply the amount of energy that you are legally allowed to radiate from your antenna, every second.

If the antenna radiates in all directions (isotopically), it is possible to put 4 Watts into the antenna and the EIRP would be 4 Watts out. But if the antenna focuses all this energy into a beam which has e.g. 10x the intensity which it would otherwise have, then if the input is 4 Watts into the antenna, it could effectively be radiating 4x10 = 40 Watts EIRP out of it (in the beam) and be violating the regulation in the direction the antenna is pointing.

Antennas do not just transmit, they also receive. To recover the ID information from a tag, the RF signal has to be stronger than any unwanted background electrical noise. If a signal is weak, you may need a high-gain antenna to capture enough RF energy and a sensitive receiver to put this into. This way it is possible to get enough RF energy to enable a recovery of the ID information [7].

4.1.3 Tag

Modern tags are mostly well made and have a bigger RAM. They are also more robust by the structure and from the operation point of view than they used to be. RW times are most of the times greatly underestimated in the data sheets. For Ginolis there were four different kinds of solutions which could be used in various applications. For the user recognition the basic keychain such as in the figure 8, works best. There should be still an option to have an ID card type version, such as in the figure 10, available if the user so chooses. A printable tag, as in the figure 9, is a great and cheap solution for an asset that locates in the normal office environment. The choice for the sample cassette shown in the figure 5 was a button tag, such as in the figure11. The reason for this was that it was the easiest to implement in different solutions, it has a decent amount of options of the RFID/NFC chips and it is a chemical resistant.

FIGURE 8. Keychain tag. User recognition.

FIGURE 9. Printed circuit tag.

FIGURE 10. Card tag.

FIGURE 11. Button tag.

The best RFID range is archived when the tag is facing the reader. For example, in a factory it is often easy to mount a reader under a conveyor so that it always faces the tagged items that are in a fixed position when passing over the reader. The worst RFID range is achieved when the tag is edge-on to the reader. This is because the RF is the weakest when edge-on. This can also be accomplished by having a pile of randomly mixed tagged items. Some tags will be facing the RFID reader, others will have their edges pointing to the reader and most tags will be somewhere in between.

Tags have to work in all kinds of surroundings, both indoors and outdoors. Mostly because all the solutions where the tags will be implemented are unknown. They inevitably have to work in situations where they are in contact with substances that may dramatically reduce the strength of the RF energy carrying the ID information. In Ginolis case it will be the disinfection phase. Liquids, such as water, can absorb RF (especially at microwave frequencies) and metals can shield or reflect RF energy.

Some tags are designed to minimize the effects caused by RF reflections, by processing the reflected signals that arrive at slightly different times, because some tags take slightly longer paths than others and it takes them longer to get to the receiver.

There are some simple ways how to improve the range of the transmission. One way is to have two reader antennas at right angles to each other. In that way, if a tag is edge-on to one antenna, it will be facing the other. Another way is to put two tags in each item at right angles. In that way, if one tag is edge-on to the antenna, the other will be facing it. However this will add expenses to the system. This was one option when Ginolis was thinking of having two tags in one cassette. One more way is to move tags or the reader so that the relative position changes. In that way, the angles change and a tag that was on a difficult reading angle before, once moved, may become readable after its angle becomes more favorable.

Some features of different tag types are shown in the table 1.

TABLE 1. Tag type comparizon.

Tag	**UID (bytes)**	**Memory Type**	**User Memory Size (bytes)**	**R**	**RW**	**Data Transfer (kbit/s)**	**Data Retention (Write cycles)**
Mifare Classic 1K	4	EEPROM	716		X	106	10 Years, 100.000 cycles
Mifare Ultralight	7	EEPROM	46	X	X	106	10 Years, 100.000 cycles
NTAG	7	EEPROM	48		X	106	20 Years, 200.000 cycles
NTAG216	7	EEPROM	888		X	106	10 Years, 100.000 cycles

4.1.4 Frequency

RFID range is affected by the operating frequency. Here are the four most common Radio Frequency bands for RFID, Low Frequency (LF) 125 to 134 KHz band, High Frequency (HF) 13.56 MHz, Ultra High Frequency (UHF) 433 MHZ and 860 to 956 MHz band and Microwave Frequency 2.45 to 5.8 GHz band.

The characteristics of each band affect the RFID range differently. In general, the higher the frequency, the greater is the range. RF radiation has more energy at the higher frequencies and so the RF field can influence RFID tags that are further away. Lower frequencies (LF) usually mean a shorter RFID range. LF RFID devices use the so-called Near Field Effect. This uses the magnetic component of the electromagnetic energy and this couples the tag and reader over only very short distances of typically up to half a meter. This is good in applications, like in card readers or user recognition key tags, where you bring the tag close to the reader. The influence falls off very rapidly when moving the tag away from the reader. Approximately, if the separation distance is doubled, the RF intensity falls, not to half of what it was, but to one eighth. When the separation distance is tripled, the RF intensity falls to one twenty-seventh of what it was. This effect limits the amount of power that can be transferred from the reader to the tag as they move further apart. This is significant if the tag does not have a battery and is relying on harvesting some of the radiated energy from the reader to power its microchip.

When going in the higher frequencies, there can be some limitations. At higher frequencies the RF can be more easily obstructed or absorbed by objects in and around the line of sight between the reader and the tags.

When you read an RFID tag, data is transferred between the tag and the reader. RFID frequencies affect the maximum transfer speed. A higher frequency makes reading tags fastest possible. In the case of Ginolis they need to read hundreds of tags at the same time and if the tags are moving, this can be very important. The system do not really read the tags at the same time. They are actually read one at a time, but the time it takes to read an RFID tag is so short that it appears to be simultaneous.

The higher RFID frequencies are affected more by conducting materials (especially metal objects) that are nearby. These can reflect, reduce or totally block the RF signal. LF RFID frequencies are far less susceptible to nearby conducting materials as the signals can often go around them.

In short, the selected frequency for the Ginolis needs to be somewhere in between the common band area, HF 13,56MHz.

4.2 Evaluation Kit

For an evaluation kit I chose an Arduino Uno R3 board. The main reason for this was that the Arduino board is very flexible and easy to program. It was the most fluent way to start prototyping this technology. For Arduino there was already some RFID readers that could be easy to integrate to the microcontroller. For RFID I chose an NFC/RFID module made by a company called Libelium. One reason for picking this module was that it uses the NXP PN532 chip and it is fully compatible with Xbee shields for a Arduino board. Also, it had a separate antenna part so that it could be easier to test different kinds of antenna solutions [8].

After getting all this together, I realized that it is not possible to make a working RFID reader with these parts.

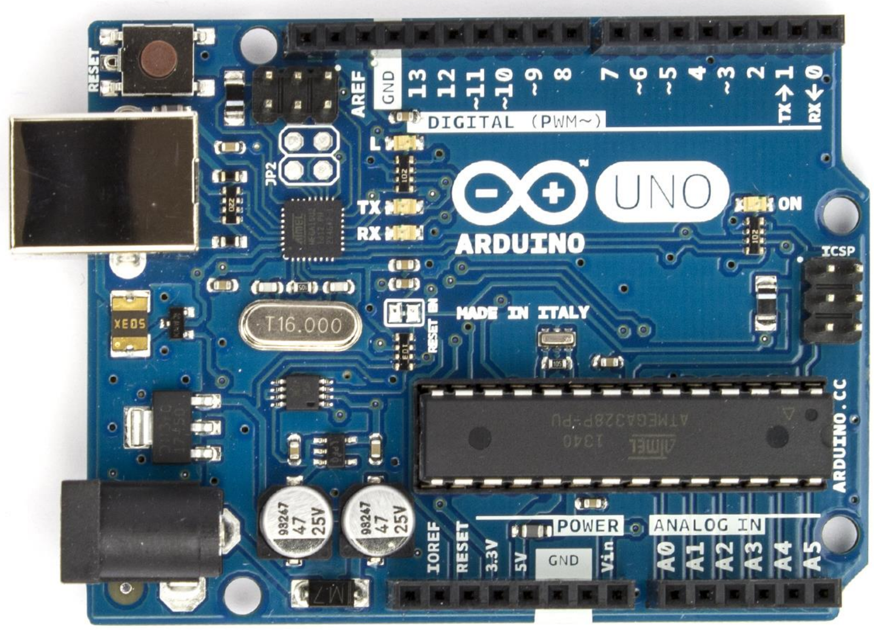

FIGURE 12. Arduino Uno.

Arduino is an ATmega328 based microcontroller board. There are 14 digital IO pins, which are more than enough for this project. Each digital pin can be used as an input or output. They operate at 5Volts and each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor. The RFID module needs only 4 pins: TX, RX, GND and Vcc. The board takes a 5V operating voltage directly from a USB connection. This makes it easy for a fast and flexible use because there are no other power sources or communication connections needed.

Arduino can produce a maximum a 50mA current for it 3.3V pin. This was the only problem when trying to connect the PN532 module to the microcontroller board. PN532 needs at the peak the current of 150 mA [14].

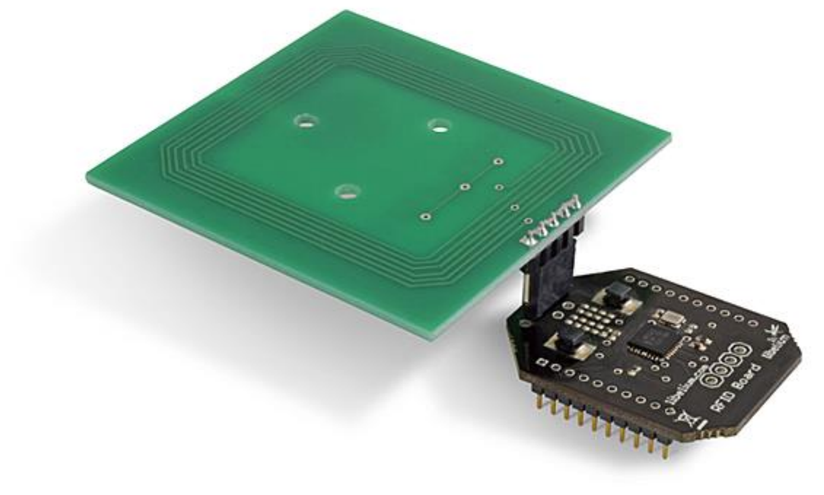

FIGURE 13. PN532 RFID evaluation module including antenna.

Figure 13. below shows an NXP PN532 RFID module for Arduino. This module includes the antenna [15].

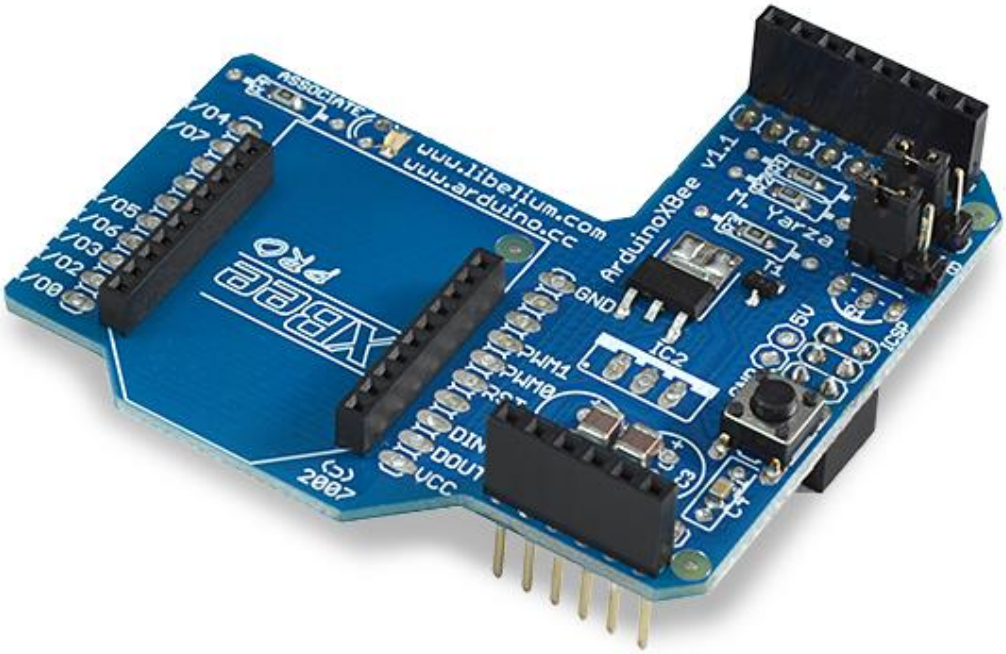

FIGURE 14. Arduino Xbee shield.

An Arduino Xbee shield mounts directly to the Arduino Uno board having a 3.3V power regulation and MOSFET level shifting on board. This is the main reason for using this shield in this prototype although PN532 is not the module for what the shield is designed to. Using this shield was extremely easy because the pins which were needed to make this thing work at the PN532 module was exactly the same as in the Xbee module as shown in this picture.

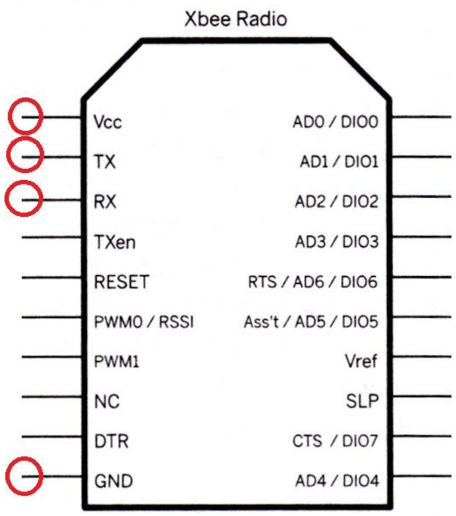

FIGURE 15. Xbee radio pin order.

The only problem that this shield brought with it was that during the programming phase the shield needed to sever from the Arduino. For testing, the reset button for resetting the whole kit was a welcome addition [16].

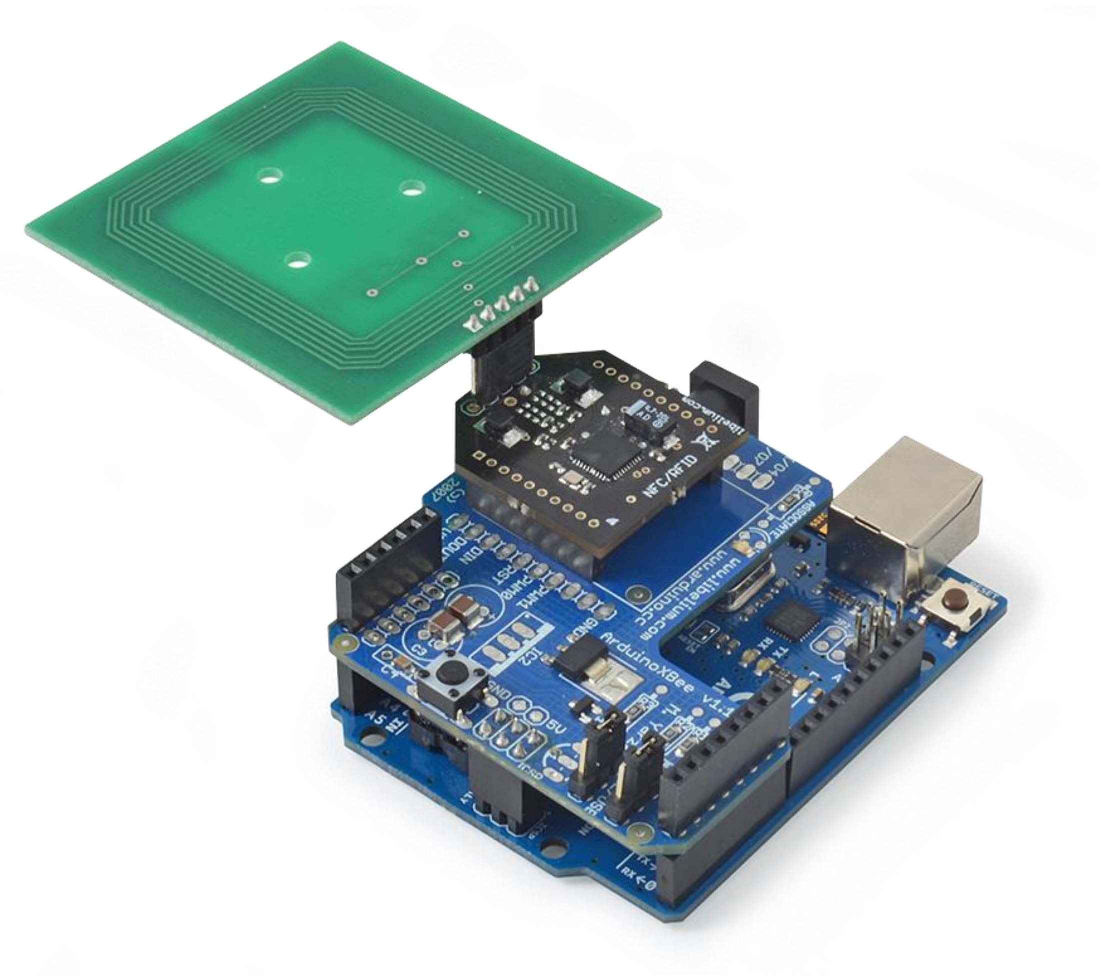

FIGURE 16. Complete kit for testing the operations of the PN532.

4.3 Consulting

For consultation I used a couple of different companies and also some private individuals for just to be sure about my decisions involving the hardware. The reason for this kind of approach was mainly that I wanted to be sure of all the choices I made and to learn something unwritten experiences that only years of experience could teach to an engineer. It was nice to find out that these consultants supported my decisions about the NXP PN532 chip, the operating frequency and the tag types.

Some of the consultants where picked according to the recommendations of my thesis supervisor from the school and some from the Ginolis.

Idesco Oy took nicely the idea that I would like to just visit them and get some information for my thesis. From Idesco I met CEO Jani Valtonen. He kept for a nearly 2-hour-long private presentation for me about the history of RFID and the technology of their company about the technology of RFID, the standards in the field, choosing the right tag and about their own products.

I found out there that it could be possible to fit all the components in one board including the antenna. Mr. Valtonen said that they have found a solution to make this kind of PCB without having the interference from the antenna to the IC. He was not willing to reveal that how they had been able to make this solution.

Ohmix Oy also met me in open mind. From there I met Harri Piltonen. He has over 25 years of experience in HW designing. He is also the man who designed for the Tracker Oy, a company that sells and develops GPS dog tracking technology.

To my surprise, I found out that the consultants did not agree with some of the things in the RFID field. Mainly, the disagreement was about the RFID circuit positioning in the PCB cording to the antenna, i.e. can the antenna be in the same PCB with the circuit, and more exactly can the circuit be in the middle of the antenna.

I tried to get some information from RFIDLab Finland Oy, but I never got a response to my email inquiry.

Confidex is the world’s leading supplier of high performing contactless ticketing and RFID tag solutions and services. From there I started to find out a reliable tag distributer which can fill all the needs for Ginlolis tag. One key feature for searching information from this point of view was that it was necessary to find a product which has a long lifespan. Confidex recommended a Finnish company called Top Tunniste.

NXP was the manufacturer of the RFID IC used in this work. From there I wanted to find details about the antenna attributes. The biggest question was if the PN532 circuit can tolerate the inductance in my PCB design.

5 IMPLEMENTATION

When designing the PCB, there were many ways to make the RFID module. The biggest problem was to find the most useful design.

There were two main ideas how to make the RFID reader. The first one became a failure because the antenna connector was located in the wrong place. There were no chance of using the SMA terminal. The result of this would have been bad or no transmit power. The antenna started from the root of PN532. I found out that the antenna needs to be designed right next to the PN532.

Another main idea was that that there is no PIC32 at the PCB. This way the data is transferred straight through high speed UART. All the components would be located in the middle of the antenna loop. That would there be electromagnetic induction causing some problems for activity of the PN532, consultants had very different opinions about this issue.

The final idea came when studying the impedance effect of this kind of loop antenna in various sizes. From this came the assurance that all the components, the antenna, PIC32 and the PN532 could be in the same PCB.

5.1 Hardware

This chapter will explain the hardware and the PCB design. In the first design shown in the figure 17 there were already the final ideas implemented.

This schema in the figure 17 is shown here because it was a major step in the fault location and for the testing. In the schema there is a small error in wiring. The 3.3V operating voltage is going in the TVDD and in the antenna in PN532. TX1 should be the antenna connection and in this it is left empty. Fixing this was easy and the second layout is shown in the figure 18.

Having this design fault was a result of a hectic timetable. Because of this, there where no one who could do the final check for the PCB schema before it went to production. It took an unreasonably long time to locate this fault. When the code was ready to be programmed in the RFID module the testing could start. When nothing happened with the program, it was noticed that code and the PCB needed to be double checked. The first idea was that the code is the problem. After having many failures when testing the code, the scope of the PCB started. Going through the PBC and schema one by one was a long process that required patience and vigilance. This was the way to find this little glitch.

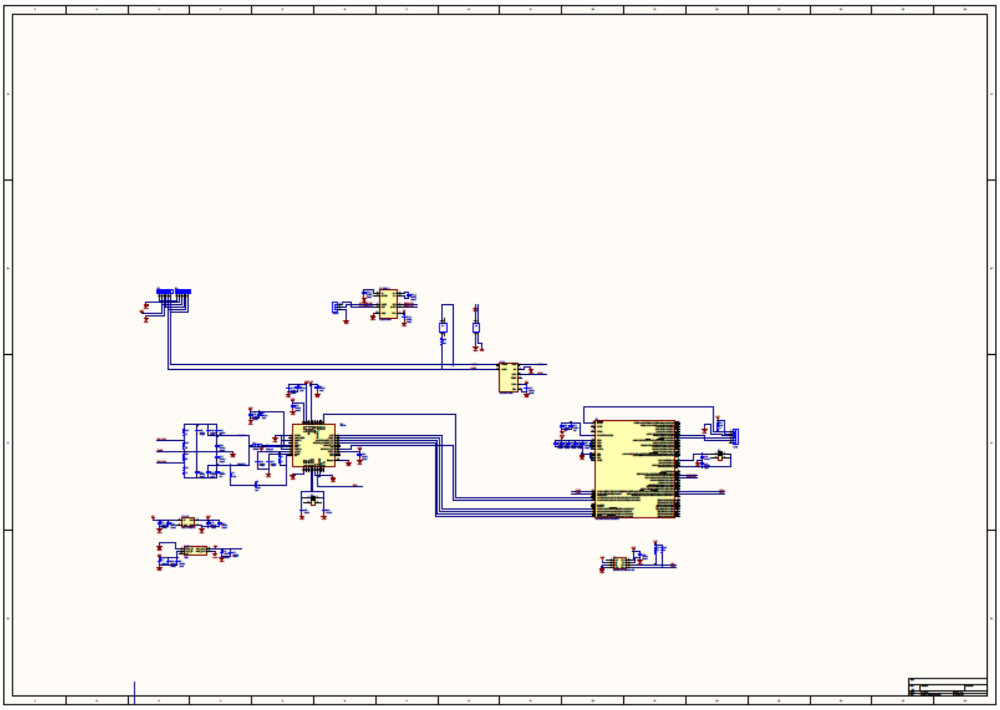

FIGURE 17. Schematic, first design.

When fixing the PCB schema, there came some improvement ideas from the Ginolis. They wanted indication led lights on the board for a test purpose. Then there was the idea of rethinking the dip switch functions, i.e. should there be any of them or should the functionality be I2C or SPI instead of SPI or UART.

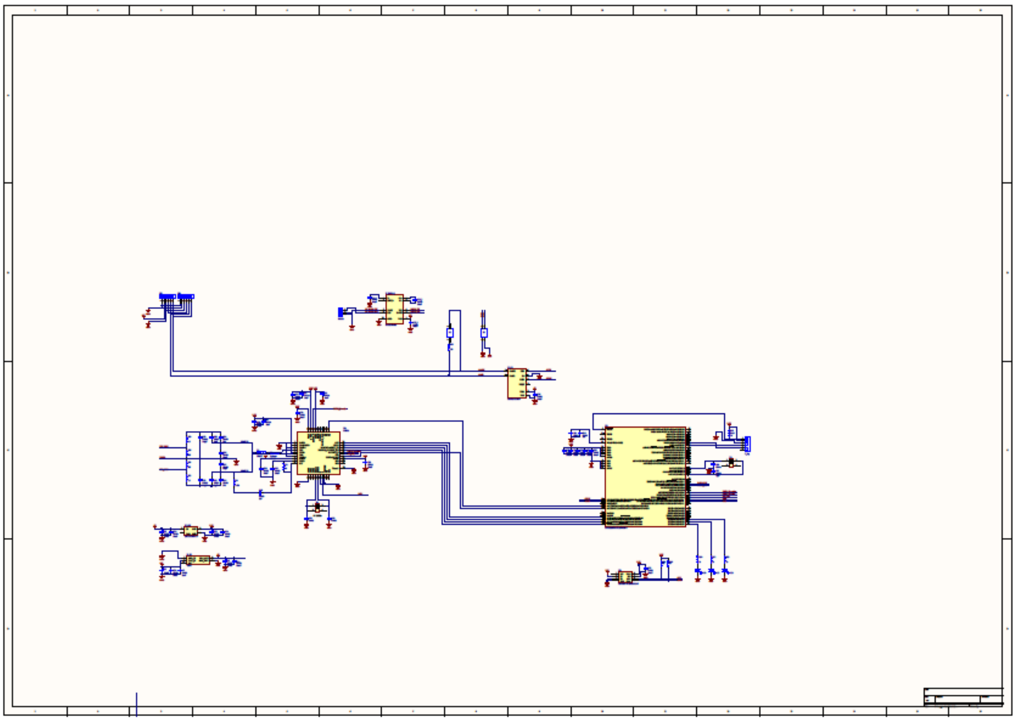

FIGURE 18. Schematic, final design.

In the final version as seen in the Figure 18, some indicator leds were added for testing and for indicating the operation of the RFID module.

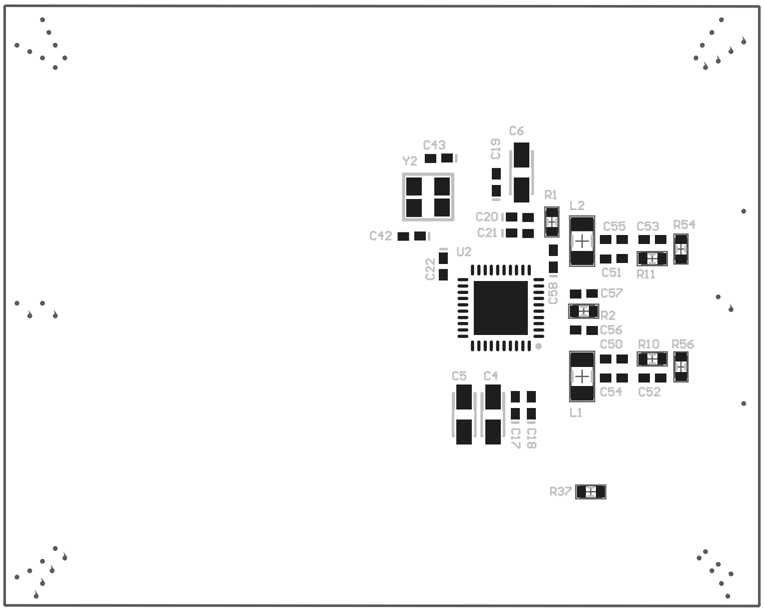

FIGURE 19. Component assemble layout, radio side.

The radio components in the PCB took the least space in the whole design as seen in the figure 19. By separating the radio and the controller part module would have new ways to fit in various locations. This was not nessessary in this time, thus the ease of use and cost issue were the determining factors in the design.

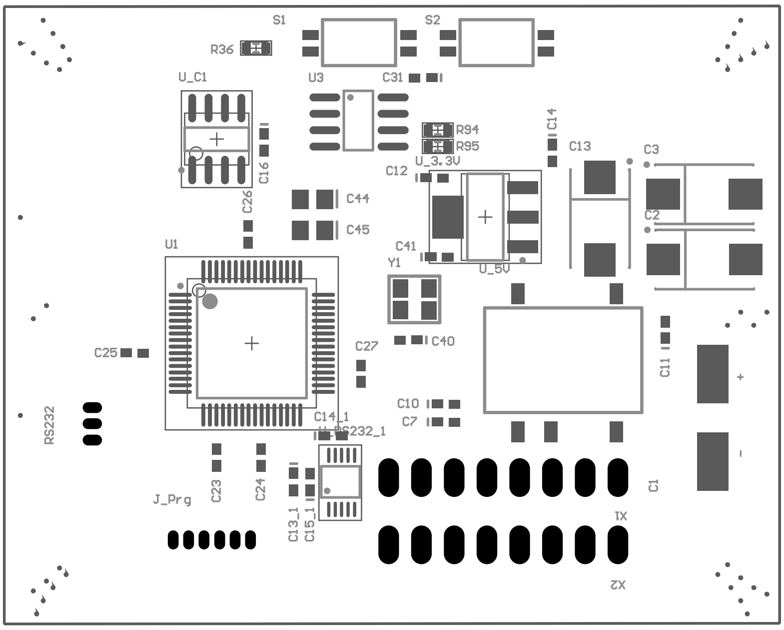

FIGURE 20. Component assemble layout, power and controller side.

The figure 20 shows the amount of extra components that need to be fitted in the same PCB for having all in one design. The most sizable components here are the power alteration parts. The power through the CAN bus comes in 24volts, thus it needs to be processed for two different points, one 5volt and one 3.3volt [13].

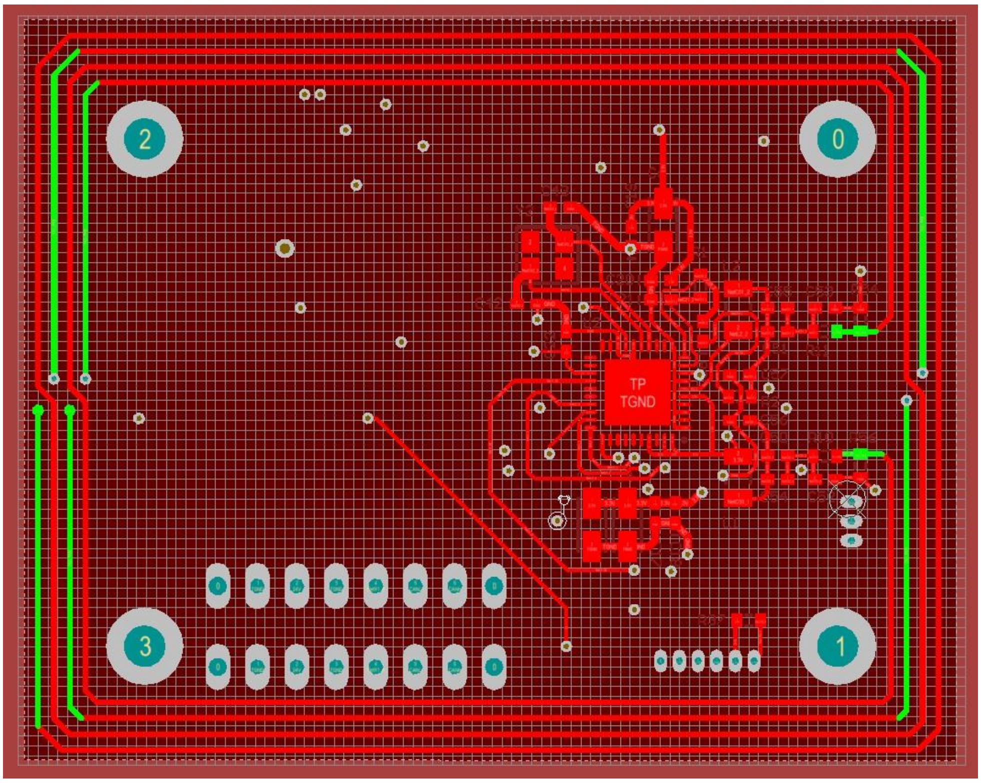

FIGURE 21. PCB wiring graph, layer 1, radio.

The figure 21 shows the design of the antenna. It is just a loop that comes from the PN532 through the fitting components.

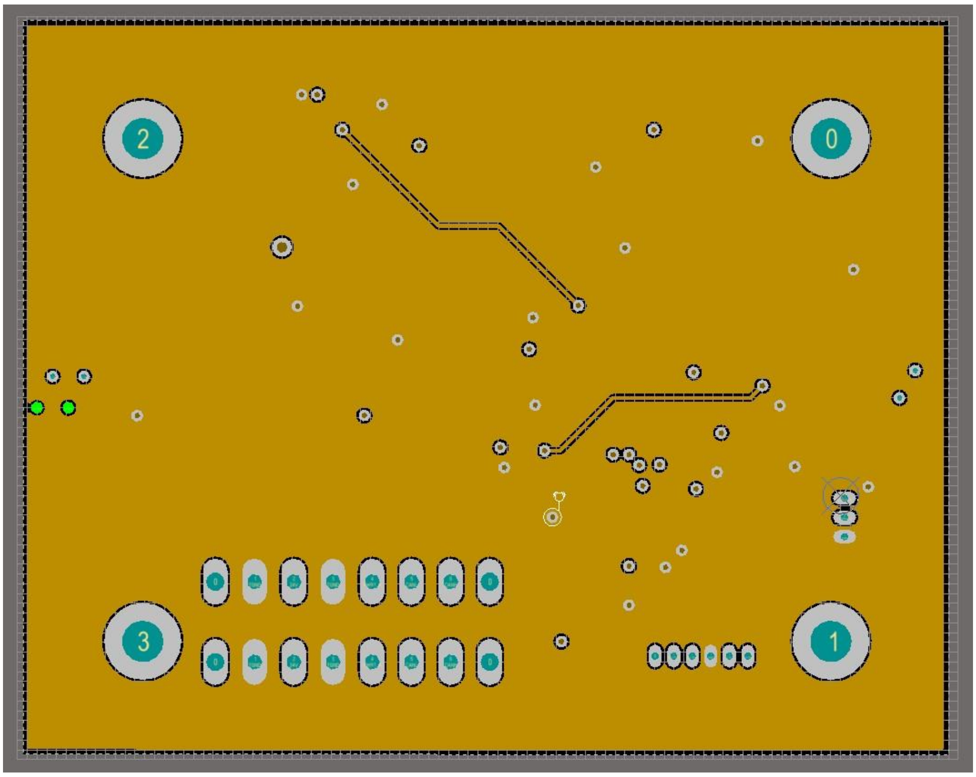

FIGURE 22. PCB wiring graph, layer 2, Vcc.

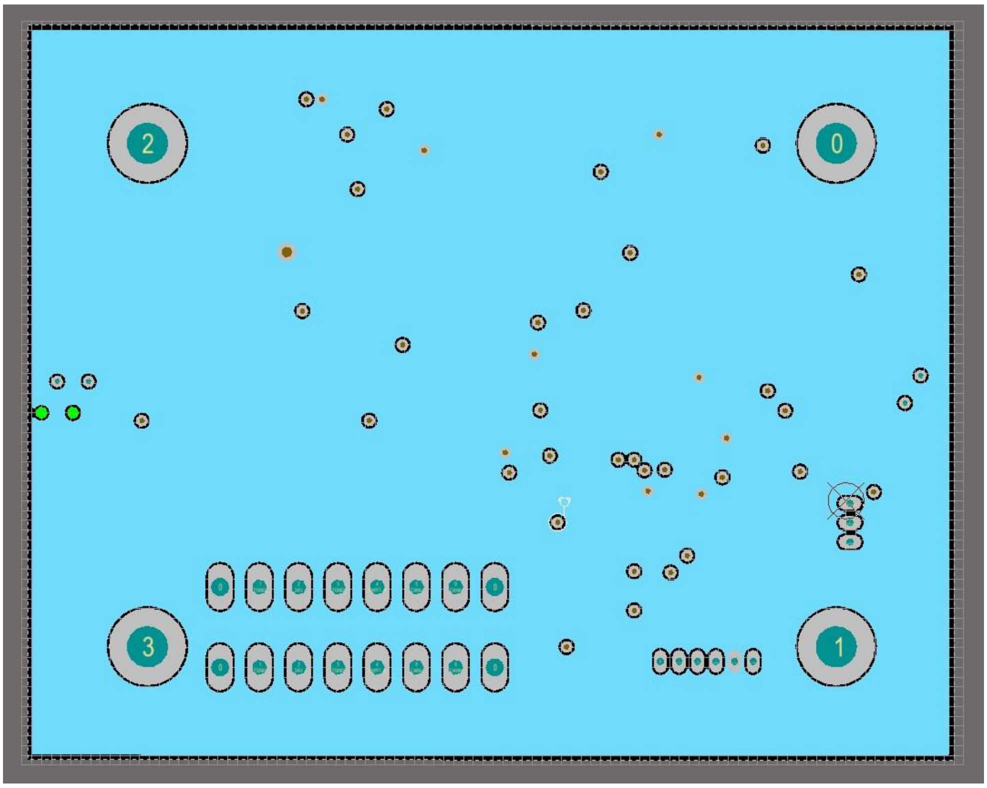

FIGURE 23. PCB wiring graph, layer 3, GND.

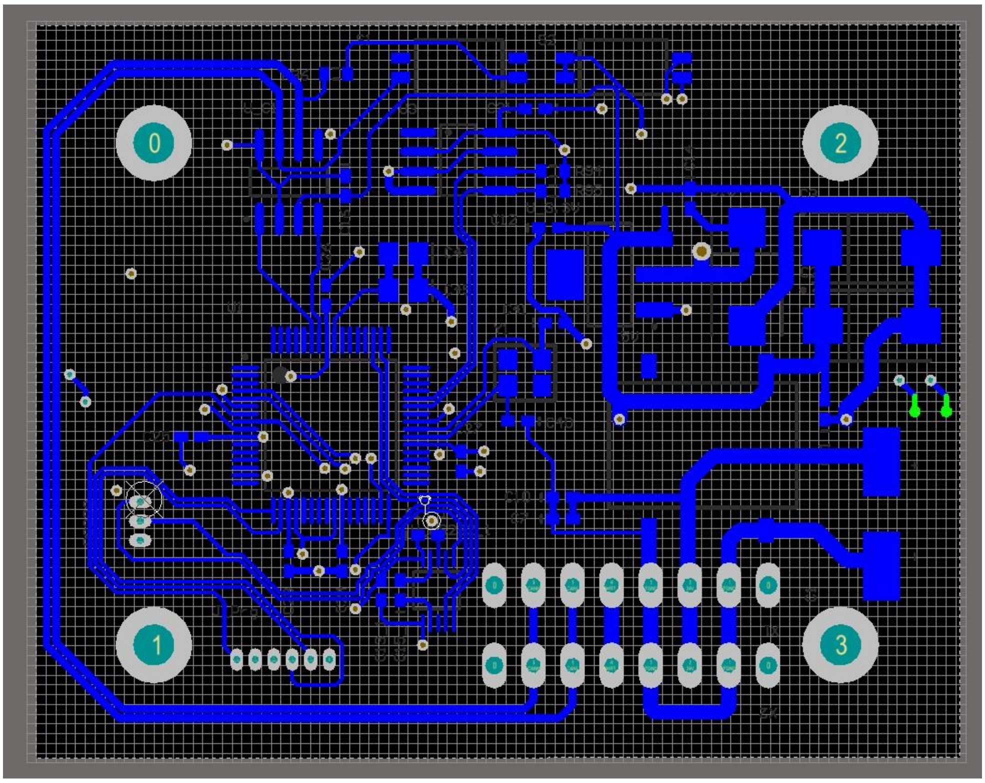

FIGURE 24. PCB wiring graph, layer 4, power and controller.

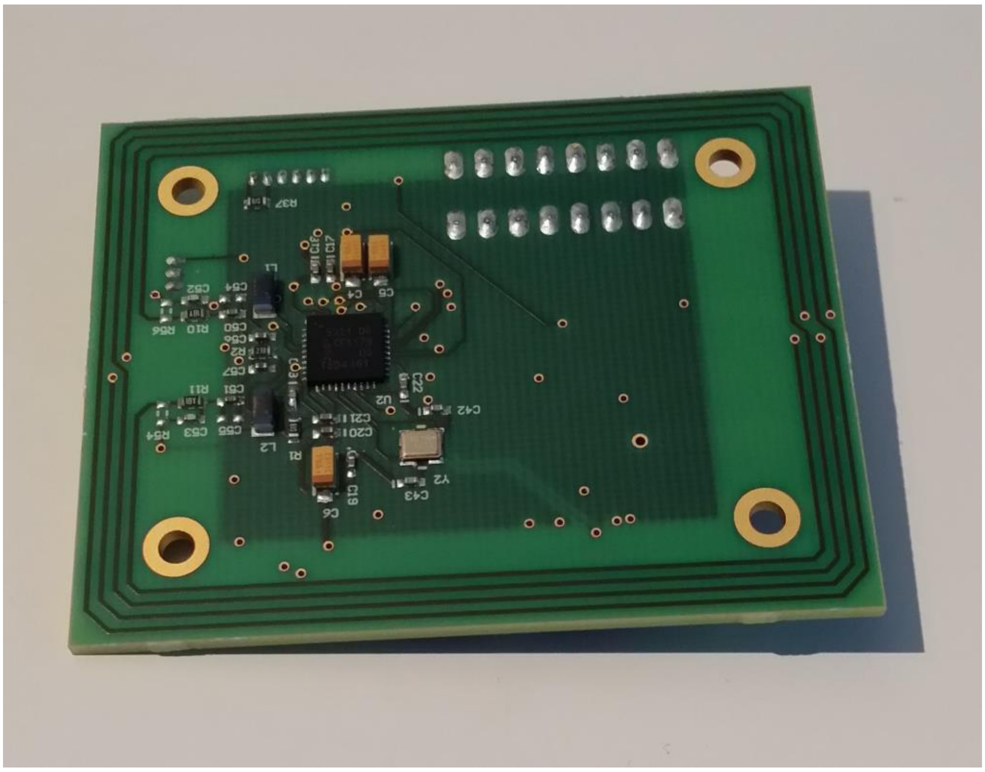

FIGURE 25. Final RFID module, radio.

The Figure 25 shows the final version of the RFID modules radio side. There is a small final change that can not be found in this document. The Vcc and GND layers have been shrunk so that they will not reach the width and height of the antenna. This way there is the least amount of interference from these layers.

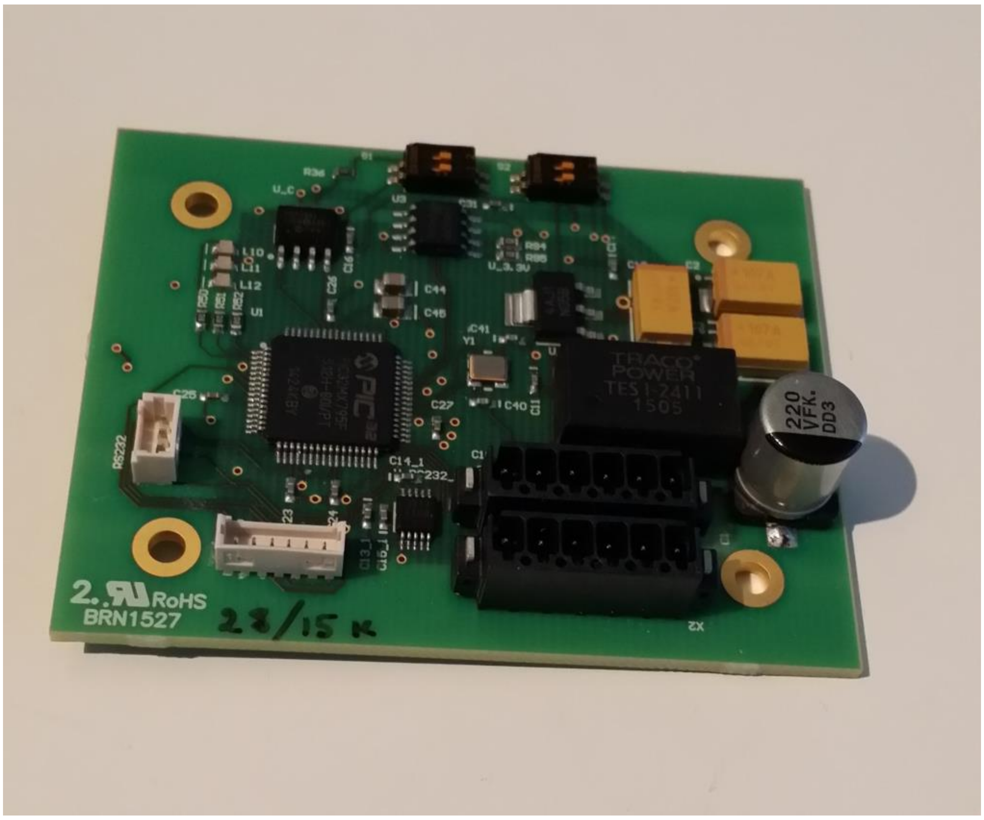

FIGURE 26. Final RFID module, power and controller.

The final version of the controller side of the RFID module is shown in the figure 26. Here it is possible to see how much space the power regulating components took from the PCB.

5.2 Software

How the program should work is presented here in the figure 27. The diagram is divided into three main parts. The first part is Delilah. This part is completely the area of Ginolis and connects to the RFID module by the CAN bus.

The second part is the RFID module. The diagram shows that the information comes and goes through two access locations. The first access point is from PIC32 to Delilah, where the user can operate the functionality of the module by reading or writing the tags. The second access point is how the RFID module influences the tags.

The third part is the read and write operation among the RFID module and tags. Tags are divided into two main operations and category, read and write user tags and read only cassette tags.

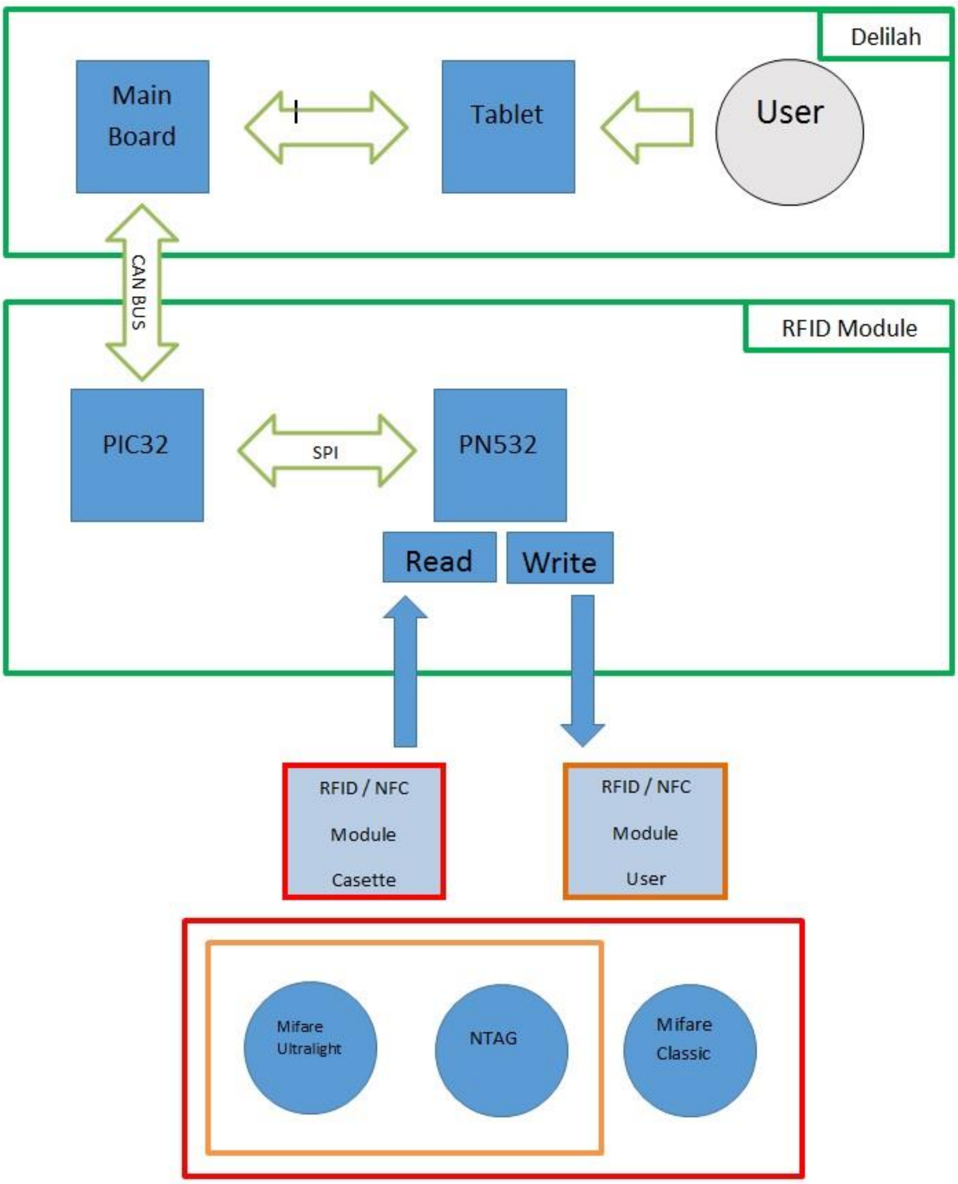

FIGURE 27. Operating graph.

6 TESTING

The testing phase is not fully performed in this work. The final version of the magnetic table and the whole sample processing system were uncompleted due to the delays that took place in Ginolis. The final version of the RFID module has not been tested by using any standard test plan. An applicable test plan for this kind of device would have been the IEEE 829 standard based test plan [6]. I would have included a series of software and system testing cases. Each case would have ended in a pass or fail conclusion.

The testing was done in three different sections. The first test was a Proto testing with Arduino evaluation kit. Arduino evaluation kit test was performed just by using a simple tape measurement to see the effect of the magnetic glass table for the radio signal.

The second test involved the environment variables for the tag. For this needed to find out the liquids that will be involved in the process which the cassette will go through. This was an endurance test for the tag.

The third test was the final testing with the final RFID module.

6.1 Environment

There are no environmental changes for the Delilah processing system. The complete system was designed for indoor use only. Some variables could have affected for the RFID module when it is inserted in the socket where it was supposed to operate in Delilah. It was not possible to perform this test due to the timetable issues.

There were some environmental effects on the tag that is attached to the sample cassette. This test was performed together with the laboratory engineer from Ginolis.

6.2 Test Case

The final test case was not performed.

6.2.1 Evaluation Board

The test done by using the evaluation kit. The idea of this test was to find out the damping effect caused by the magnetic table. For the test there were only two pieces of 4mm glass panels. Ginolis estimated that the final magnetic table will be 6mm thick, thus the test needed to be done by using a thickness of 4mm and 8mm for getting enough information about the effect.

Under the glass was the antenna unit of the evaluation kit. The height of this varied. The highest height where the tag is still readable was measured on the top of the glass. Crossing from tag to tag was just for making sure that the reader does not cross read other tags at the same time.

The tags in this case were only the key chain and the card type.

TABLE 2. Damping effect measurements.

Keyring Tag			
Glass 8mm	**Reader to Glass**	**Tag to Glass (mm)**	**Reading Crossing Tag to Tag (mm)**
	10mm	25	8
	8mm	25	10
	6mm	28	12
	4mm	29	12
	2mm	29	12
Glass 4mm	**Reader to Glass**	**Tag to Glass (mm)**	**Reading Crossing Tag to Tag (mm)**
	10mm	29	10
	8mm	29	10
	6mm	30	12
	4mm	32	12
	2mm	33	12
Card Tag			

Glass 8mm	Reader to Glass	Tag to Glass (mm)	Reading Crossing Tag to Tag (mm)
	10mm	58	6
	8mm	59	8
	6mm	60	8
	4mm	62	28
	2mm	64	28
Glass 4mm	**Reader to Glass**	**Tag to Glass (mm)**	**Reading Crossing Tag to Tag (mm)**
	10mm	60	30
	8mm	62	34
	6mm	63	35
	4mm	68	37
	2mm	70	37
Keyring			
No Glass	**No Glass**	**Tag to Glass (mm)**	**Reading Crossing Tag to Tag (mm)**
	0	42	31
Card			
No Glass	**No Glass**	**Tag to Glass (mm)**	**Reading Crossing Tag to Tag (mm)**
	0	77	32

As a summary;

- The keyring shown in the figure 8 had an average reading distance of 27.2mm with a damping of 1.8mm, using a 4mm glass, and 2.4mm when using an 8mm glass.
- The card tag in the figure 10 had an average reading distance of 60,6mm with a damping of 3.4mm, using a 4mm glass, and 5.4mm when using an 8mm glass.

6.2.2 Final Module

The final version of the RFID module was tested fast just by testing if it will read a distance or not, and what distance it will read. The module worked alright and the reading was successful. There was a little problem with the operating distance. The tag reading happened in the range up to 20mm.

6.2.3 Tag Test

The physical attributes of the tag needed to be tested in case that it would fail in the field use. In the case, where the tag has the hardest environment, is the sterilization phase. In this phase it will go through some alcohol like a substance that makes the sterilization for the cassette to which the tag is attached. This happens fast and leaves the tag in a dry environment after the process. The test was performed so that it would meet the worst possible scenario for the tag. The test was performed by a laboratory engineer Topi Hintsala from Ginolis. As a result, the tag will be suitable for the task it was intended. Below is the complete report from Mr. Hintsala.

“30.3.2015

Chip was in 95% ethanol for 1 hour Ethanol was still clear (no color) after the hour Chip mass was 1509.64 mg before ethanol soak

Mass after ethanol soak:

Some ethanol has gone inside the chip?

Weight was recorded 45 min after ethanol soak

2 more hours was waited to see what happens

Mass 2h later:

Not much change..

31.3.2015

1510.55 mg. “

7 CONCLUSIONS

In the end the requirements were discovered for the final RFID module although it was the challenging and biggest task in this thesis. During finding the requirements for RFID module, the selecting of the technology was in process. Doing these two tasks hand in hand gave the realization how the things interact with each other. This gave the idea to have components that have the most diverse in use and are common in venture use.

Designing the hardware appeared to be a challenge too. There were some component groups that were modified from the Ginolis PCB libraries. One of these was the power regulation components. Connecting the PIC32 and PN532 together needed some research to be done about, what should have been the communication between these controllers, I2C, SPI or the HUART. Choosing the SPI just for having a new challenge, turned out to be a failure for the first PCB design. After having some difficulties in finding the problem, the second PCB design turned out to be a success. The final test in the RFID modules working environment was not possible due to time issues, but a fast test to see the operation of the module was done.

The technology evolves such speed that it will be certain that in the close future there will be a newer and more efficient model of the RFID IC available. Changing the PN532 will be one of the biggest steps in the future. The manufacturer informed that there will probably be no need of schematics changes when replacing the chip to a new model, the socket should stay the same. There is still a chance that the antenna design will not be so efficient in the new model. Therefore in that case it will need some tweaking.

In my opinion there needs to be different models of antenna fitting to get more options for the module in specific locations.

An antenna should be designed to be a separate component from the controlling board. There is already an existing plan how to make this possible. In the next version the antenna unit will be a pad solder unit made from a flexible printable circuit board. This needs to have some research for figuring out if there could be a possibility to have this as a see through option. Otherwise, there will be a ferrite layer behind the transmitting side for a better signal. If the antenna will be a separate component, the mainboard loses some of its size for the advantage of the usability.

As a whole, this was a challenging topic. When the plans for Delilah lived together with the RFID module, everything was a little bit more complicated to design. This was an unwanted feature that gave a more challenging and intriguing work. During this kind of process, I found out that rapidly changing things that needed some flexibility were my asset. Thus the RDIF module lived through the whole process and will still be living and moulding.

From this, I learned so much. The topic was chosen because I knew almost nothing of designing an RFID reader. Some new fields needed to be studied. I regret that I was not able to design the antenna for this. By using the ready-made models for the antenna, it gave the biggest uncertainly of the functionality of the RFID module.

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