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RFID

Investigation of selectivity, comparison between active and passive transponders

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Abstract

Evaluation of RFID

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This is a report where an approach to use a patch antenna as the transmit device when sending radio waves in a RFID system has been investigated. The project is successful in the sense that the antenna is working as imagined, the antenna parameters may however not be satisfactory. The antenna read range may be a little to insufficient when the RFID tags are worn by humans which is one of the underlying requirement for the system this antenna was design for. Tags which are rotated from a vertical alignment also reduce the effectiveness of the antenna even more to a point which is not acceptable. Suggestions for how to further improve the antenna are given and addresses the issues mentioned above.

The report first contains a brief introduction to antennas in general and also information about patch antennas specifically as that was the antenna chosen to be constructed and tested for this system as it theoretically seemed very fitting. A working antenna was constructed and tested in a real environment together with simulations of the antenna to further examine it. The finished antenna is evaluated with possible advantages and drawbacks being discussed together with mentioning how then antenna could be improved for better performance.

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Sammanfattning

Den här rapporten har undersökt hur det skulle gå att använda en patchantenn som radiosändare och mottagare I ett RFID-system. Projektet har lyckats i avseendet att antennen fungerar som tänkt, antennparametrarna är möjligtvis inte helt tillfredställande. Antennens avläsningsavstånd är möjligtvis lite för kort när RFID-taggarna bärs av människor vilket är ett av de bakomliggande kraven på det systemet som antennen var designad för. Taggar som blir roterade från en vertikal placering försämrar även det effektiviteten för antennen, till en oacceptabel nivå. Förslag på hur antenna kan förbättras ges och de problem som mämnts här tas upp.

Rapporten innehåller först en kort introduktion till antenner I allmänhet och även information specifikt om patchantenner, eftersom det var den antenn som valdes till att bli konstruerad och testad då den teoretiskt sett passade väldigt bra in på detta system. En fungerande antenn blev konstruerad och tested I en verklig omgivning, även simuleringar av antennen utfördes för att undersöka den ytterligare. Den färdiga antennen är utvärderad med diskussioner om möjliga fördelar och nackdelar samt omnämnande av hur antennen kan bli förbättrad för att ge bättre prestanda.

Acknowledgments

I would like to thank Syntronic AB for allowing me to perform my thesis work at them, with full access to their facilities as well as tools, I have thoroughly enjoyed my time there.
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Markus Jonsson

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1 Introduction

1.1 Project Description

A general RFID (Radio Frequency Identification) system consists of a three main parts; reader, antenna and tag. The RFID reader is used to create and control the power and frequency of the signals being sent to the antenna that is connected to the reader. An antenna connected to a reader is then used to communicate with the RFID tag which in themselves are small antennas with a RFID chip attached to them. There are different types of tags available where the two most used ones are passive and active tags. Passive tags draw the power needed to operate its chip and antenna directly from the electromagnetic signals sent out by the reader antenna and is therefore dependent on the reader antenna to transmit signals strong enough to allow for an acceptable tag read range. Active tags instead have a battery attached directly on the tag which allows it to transmit more powerful signals back to the reader antenna but also increases the physical size of the whole tag.

Part of the final goal of the project has been to construct and test an antenna for a reader in a passive RFID system to see how well a passive setup can perform compared to an active RFID solution. The intended use for the RFID system that the antenna have been developed for is to have tags placed on the human body to allow for identification and location monitoring inside a building when the tags are being carried past an antenna. The antennas are to be mounted on walls, or doorways, in a corridor and because of these placement requirements the antenna have to be low profile to be able to seamlessly be mounted there. This system could then be used for example in a hospital or care-taking facility to allow for more efficient monitoring of patients and also being able to monitor where personnel are located to quickly dispatch those closest to a room if a assistance alarm goes off.

When using RFID together with the human body a challenge arise where the amount of water the human body consists of attenuates RF signals. To mostly solve this the tags can be placed not directly on the skin of a person but instead with a little distance away from it. This will allow the tag to receive signals from an antenna at a reasonable range, but the antenna will still need to transmit relatively powerful signals for the passive tags to receive enough power to operate and be detectable that close to the body. Another challenge when using tags that are supposed to be worn on for example the wrist is that the size of the tag, bending the tag around the wrist or arm would worsen the performance of the tag antenna. An acceptable size for wearing on the body is also needed as it will otherwise cause discomfort on the users.

The antennas used in the experiments was constructed through milling out the design on copper laminates. The final design was checked in HFSS simulation software before constructed and also further evaluated and compared with simulations only.

1.2 Background

With the wide range of antennas that are available now there is a good chance to find an antenna that has the desired specifications. When using antennas in warehouse or product tracking the detection problem do not normally arise as most of the times the reader antennas can be placed close to the products with a tag attached to them. Because there is a large range of antennas, they all work with different parameters such as frequency, bandwidth and gain. Therefore a general purpose shelf antenna is most of the time not going to be the preferred choice although it may produce the desired result as the physical size of the antenna could be unsatisfactory, the system needs several antennas making the total cost for the system to expensive or the antenna has features that will not be used in the system. To acquire an antenna for specific system it is therefore better to design your own antenna with the system requirements in mind to allow it to better fit the kind of system that is being created.

If tags are to be placed on humans the high quantity of water in the human body will absorb a major portion of the radiation. It is therefore important that the antenna has a high gain which means most of its radiation is concentrated in one direction instead of sending radiation towards all angles around the antenna, which will cause it to not radiate as far or with as powerful signals. If most of the radiation is being directed in one direction the antennas can be placed on walls in a corridor without the fear of it picking up tags on the other side of the walls or through the roof and reading tags that aren't inside the corridor.

An active RFID solution gives a longer read range together with a more robust solution. The downside of using an active RFID system though is that the tags are battery powered and those batteries will eventually need to be replaced. A passive solution would run for as long as the tags and antennas are not physically broken. The tags for an active RFID system are also substantially larger because of needing the battery mounted together with the tag, the tags that can be used for a passive system are more suitable to be worn by humans because of the size they can be manufactured in. Passive tags draw their operating power directly from the electromagnetic radiation sent out by the antenna.

2 Theory

2.1 Antennas

Antennas are used to transmit and/or receive electromagnetic radio waves through the air. The shape and size of an antenna can differ in many ways, and are also dependent on how the antenna should operate. When broadcasting a signal with an antenna the signals are first sent through a feed towards the antenna element, where the radiation leaves the antenna to be propagated out through free space.

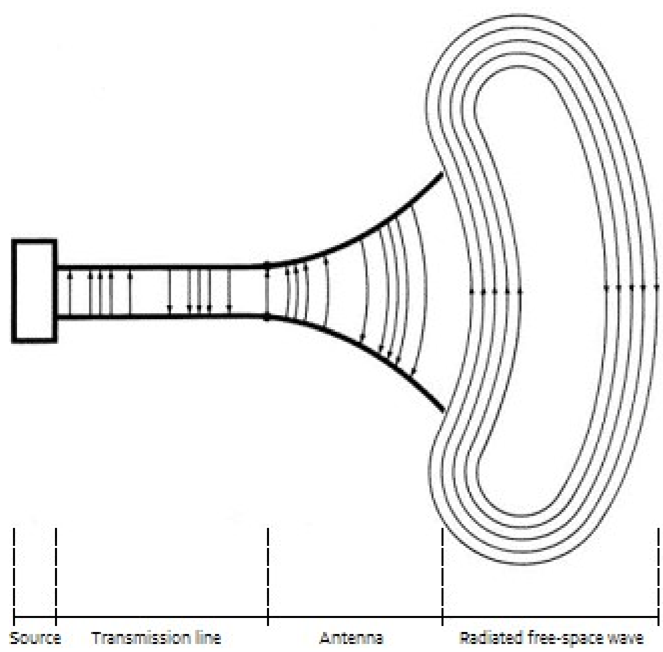

Figure 2.1: The concept of a basic antenna setup

An antenna can also transmit the radio waves in several different ways. The system where the antenna is to be used have to be evaluated to see if the radio waves need to be propagated all around the antenna or in a specific direction, for example. To have an antenna work as desired losses also have to be minimized, such as losses in the conducting materials or the air or other mediums which the radio waves will be traveling through. Reflections caused by mismatching the impedance between the feed and the antenna element can also cause the signal to lose power and impair antenna performance, how to avoid this mismatch will be discussed later in chapter 2.4 Impedance Matching.

2.2 Different types of antennas

2.2.1 Dipole

A dipole antenna is one of simplest antennas available, it is constructed by adding two conductors at the end of a regular wire. The conductors are fed at one end and placed in line with each other with a small space between them, this creates a very low profile antenna. The length of the two conductors are usually set to be a quarter of a wavelength of the desired resonance frequency of the antenna, making the total length of the whole antenna close to half a wavelength.

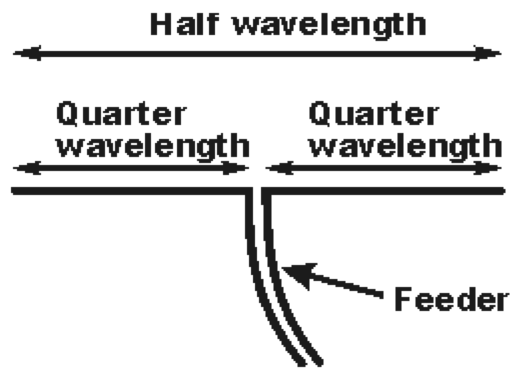

Figure 2.2: A dipole antenna

2.2.2 Yagi-uda

The Yagi-Uda antenna typically consists of a dipole as the driven element, together with several other conductors called reflector and directors acting as parasitic elements. The reflector is typically a little longer the the dipole and placed on one side, the directors on the other side are typically a little shorter then the dipole. This construction creates a very directional antenna compared the the simple dipole that radiates around the whole construction.

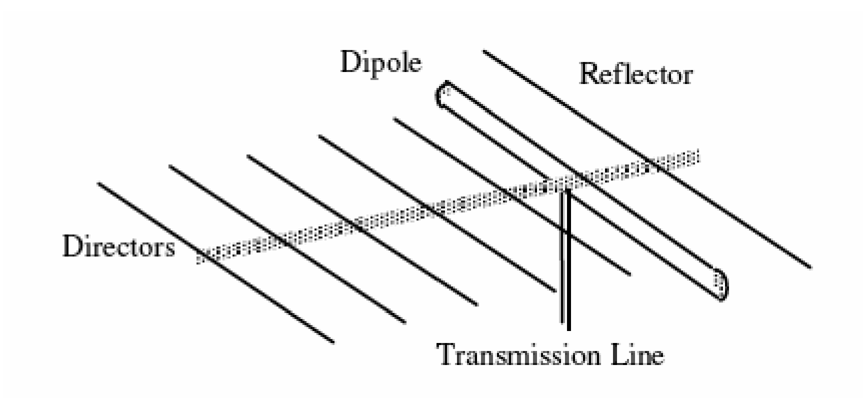

Figure 2.3: A Yagi-Uda antenna

2.2.3 Parabole

A parabolic, or dish, antenna is like the Yagi a very directional antenna. The parabolic antenna uses the dish shaped element to direct the radio waves into what can be resembled as a beam. Parabolic antennas do however need to be very large for the dish to work efficiently.

2.3 Patch Antennas

One type of antennas that are very low profile is the patch antenna. A patch antenna consists of three important parts, a patch in a thin conducting material as the top layer that in some configurations also consist of the transmission line that feeds the patch. The patch and the feed line rests upon a non-conducting substrate and as the bottom layer there is a ground plane. The patch and microstrip line are very thin in a conducting material, usually copper. The substrate will serve to keep the conducting layers on either side apart from each other which then makes current travel between these two layers through the substrate and causes the antenna to radiate. The length and width of the patch, height and dielectric constant ε_r of the substrate and dimensions of the ground plane are physical parameters that are important when constructing a patch antenna, many parameters of the finished antenna depends on these. Once the frequency of operation has been decided for the system these physical parameters can be used to calculate the dimensions for the patch antenna and once the patch dimensions are set some antenna parameters, such as input impedance and radiation pattern, will be known as well.

Patch antennas generally have a very small frequency bandwidth, but when working with RFID in Europe there exists regulations that only allow radio signal to be broadcast within a very small scope within the UHF, Ultra High Frequency, band [1] so that will not be a concern for this system. The manufacturing of a patch antenna is also very easy and cheap as they can be milled out of a laminate which is what has been done in this project, or etching the patch design directly onto a regular circuit board. It is also important to have knowledge about what kind of laminate or circuit board is used as the properties for the material are used for calculations that controls how the antenna radiates.

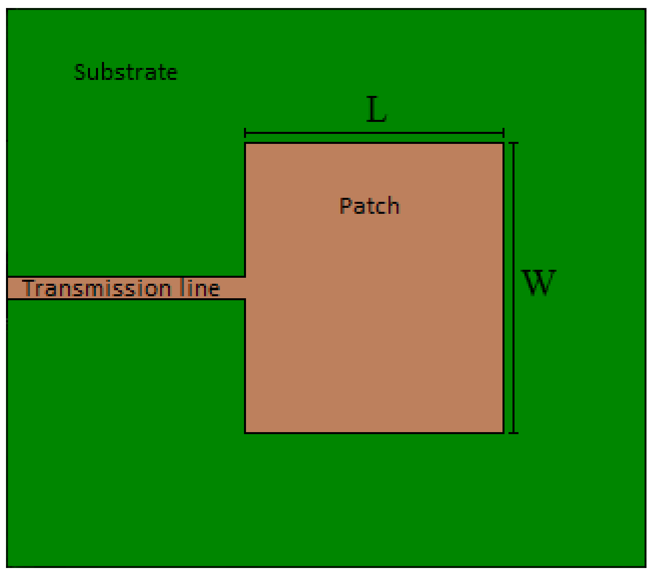

Figure 2.4: A basic patch antenna with length L and width W and a microstrip transmission line

The transmission line is what combines the cable connected at the source containing the radio signals, with the patch that propagates the radio waves through free space. When constructing the antenna through milling or etching the transmission line is often included in the top layer and usually needs to be designed specifically to match the impedances. If the transmission were to be fed at the edge the high impedance that the patch edges has [2] will cause a severe drop in the antennas performance. The impedance will be lower when the current travels to the center of the patch. This shifting in impedance when traversing from the patch edge towards the center allow two common feeding methods to easily match the impedance of the source signal with the impedance of the patch.

The length of the patch decides the resonance frequency of the antenna and has to be chosen carefully to account for fringing effects that occur along the patch edges, otherwise the patch may resonate in a slightly lower frequency the desired. The patch can also be made in a variety of trigonometric shapes depending on what properties the antenna should have. The rectangular patch antenna is one of the most common used shapes when constructing patch antennas, and it can be analyzed using either transmission line model or the cavity model. The transmission line model will treat the patch as a microstrip line to analyze its properties while the more accurate cavity model will treat the substrate as a resonance cavity with the patch and ground plane as electric conductors and 4 magnetic walls along the edges of the patch.

2.3.1 Transmission line model

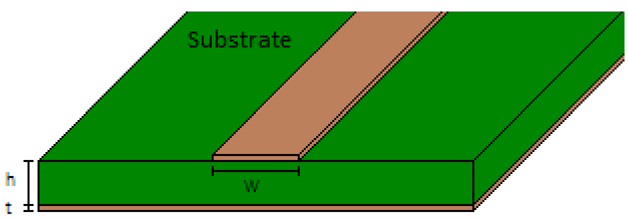

Figure 2.5: A side view of a microstrip transmission line

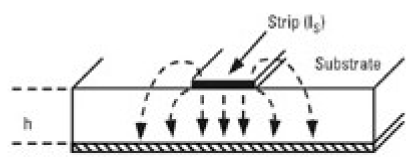

Figure 2.6: Field lines for a microstrip transmission line

Using the transmission line model to analyze a patch antenna is as indicated the easiest way but as a consequence it is also the least accurate one. There are two cases on how to use the transmission line model, one representing a thin microstrip line when $w/h < 1$ and the second case being the opposite with $w/h >> 1$. When applying this model to analyze the patch antenna the patch will be considered a wide transmission line as $w/h >> 1$. When $w/h >> 1$ and $\varepsilon_r >> 1$ the electric field lines will reside mostly in the substrate [3] as can be seen in Figure 2.6. As some parts of the field will pass through the air outside the substrate a effective dielectric constant ε_{eff} is instead used to account for parts of the waves passing through a different medium.

$$\varepsilon_{eff} = \frac{(\varepsilon r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2} \cdot \frac{1}{\sqrt{1 + 12\frac{h}{W}}}$$

When the fringing effect make the patch electrically a little longer than the physical length that has to be accounted for to have the correct physical length of the patch as the electrical length needs to equal half a wavelength of the resonance frequency, a popular expression to approximate the length extension ΔL is [1]

$$\Delta L = 0.412\text{h} \cdot \frac{(\varepsilon_{eff} + 0.3) \cdot (\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258) \cdot (\frac{W}{h} + 0.8)}$$

The electric length of the patch is then

$$L_{eff} = L + 2 \cdot \Delta L$$

As the patch is extended on both sides with ΔL, this expression is now used to get the physical length L of the patch. The width W of the patch antenna can be set as [3]

$$W = \frac{v_0}{2 \cdot fr} \cdot \sqrt{\frac{2}{\varepsilon_r + 1}}$$

Where v_0 is the velocity of light in free space and f_r is the desired resonance frequency of the antenna.

2.3.2 Cavity model

Another way to analyze the fields around the patch and inside the substrate is to consider the antenna structure as a cavity which is bound by electric conductors in the patch and the ground plane and vertical magnetic walls around the patch. This approximated model to look at the antenna is an accepted approach and when assuming the cavity radiates power approximate to the fields generated in a model like this, the computed pattern, input admittance and resonant frequency compare well with measurements [3]. Energizing the antenna will create fields between the patch and ground plane which is shown in Figure 2.7.

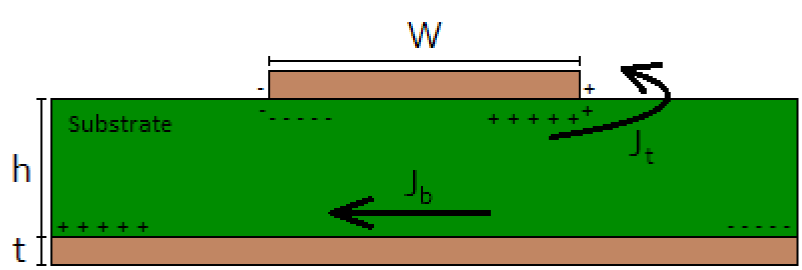

Figure 2.7: Current distribution for a patch antenna

The charge distribution between the top and bottom of the patch as well as on the ground plane will be controlled by a attractive mechanism and a repulsive mechanism. The attractive mechanism, J_b, is between the positive and negative charges inside the substrate so it will be present both on the patch bottom and on the ground plane. The repulsive mechanism, J_t, is between like charges in the patch bottom and pushes some charges to the top of the patch. The attractive mechanism will dominate when W>>h and this will cause almost no charges to be forced around the patch edges to the top of the patch [3]. The theoretically created magnetic walls of the cavity can then be treated as perfect magnetic conducting surfaces in this case because of the small amount of charges that actually pass through the walls and travel outside the patch towards the top of the patch.

2.4 Impedance Matching

The reason for matching the impedance of the patch and feed line is to avoid reflection that otherwise can arise in the cable. If the characteristic impedance for the signal traveling from the source encounters a circuit with a higher impedance parts of the waves will be reflected back towards the source to allow for the impedances to be more equal. Matching impedances is because of this very important when constructing an antenna as causing a mismatch will create a standing wave in the cable when waves traveling in both directions combine in the cable. Standing waves will cause power of the signal and actual parts of the signal to be lost in the standing wave which greatly affects the performance of the antenna negatively.

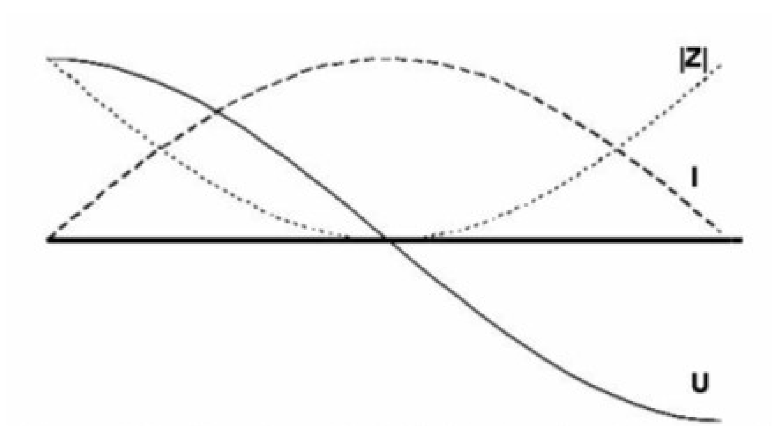

Figure 2.8: The impedance (|Z|), current (I) and voltage (U) distribution for the patch in a patch antenna

With the patch antenna fed at one side the current (I) will flow from the edge with the feed point towards the edge at the opposite side. The current also varies along the patch with a maximum in the center of the patch and minimum at the start and end of the current flow. The voltage (U) on the other hand will also vary over the patch but instead being at the maximum value at the start of the patch, and minimum value at the end. The variations in current and voltage explains why the impedance (Z) behaves as it does, by looking at Ohm's law:

$$Z = \frac{U}{I}$$

Using this expression the impedance will be near zero in the middle of the patch as the voltage is near zero. At the starting and ending patch edge the impedance will be at peak values because of the voltage peak values and the current near zero values. Using this impedance difference the patch can be fed at a point where the patch impedance is as close as possible to the source impedance in the transmission line. Two common methods for feeding a patch antenna use this technique to match the impedances.

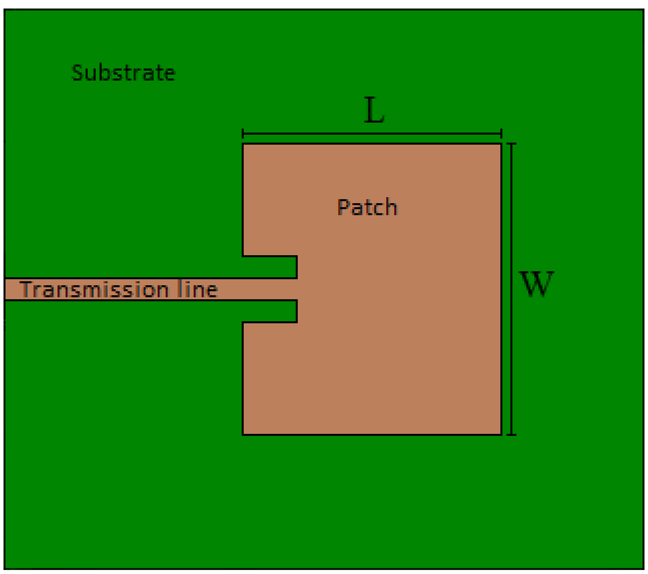

Figure 2.9: Inset-fed patch antenna

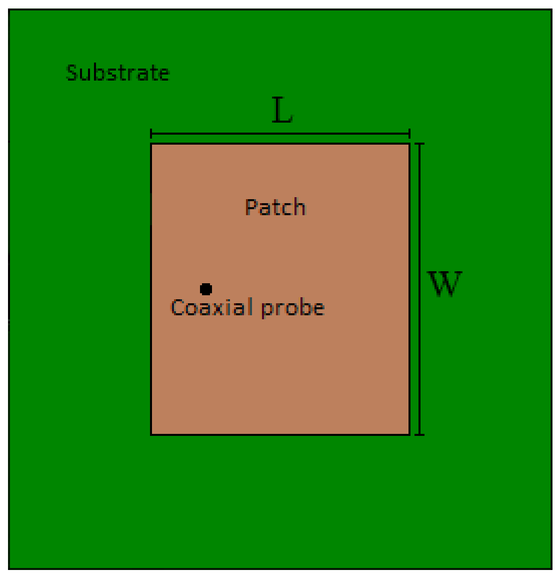

Figure 2.10: Probe-fed patch antenna

To calculate the point on the patch where the impedance would match the 50 Ω source impedance consider the two edges where fringing occurs on the patch as two radiating slots separated by a transmission line with low impedance, a equivalent circuit for the two radiating slots under the transmission line model can be seen in Figure 2.11.

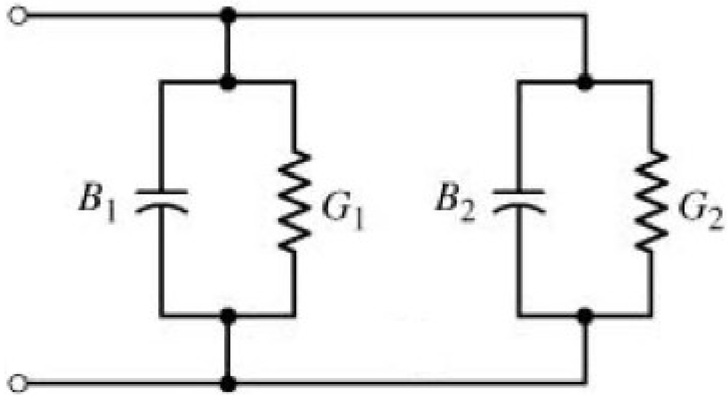

Figure 2.11: Equivalent circuit of the two radiating slots

The two slots are identical to each other [3], so that means both values of the admittance Y_1 and Y_2, conductance G_1 and G_2 and susceptance B_1 and B_2 all correspond with each other. Taking into account the effect both slots have between them the expression to find the point where to feed the antenna to match the impedances is derived by Balanis [3] and can be used when the source impedance and input impedance is known.

$$
\begin{aligned}
\underset{(y=y_o)}{R}{}_{\text{in}} &= \underset{(y=0)}{R}{}_{\text{in}} \cdot \cos^2\left(\frac{\pi}{L} \cdot y_o\right) \\
\rightarrow 50 &= 238.5 \cdot \cos^2\left(\frac{\pi}{8.246} \cdot y_o\right) \\
y_o &= \cos^{-1}\left(\sqrt{\frac{50}{238.5}}\right) \cdot \frac{8.246}{\pi} \\
y_o &\approx 2.875
\end{aligned}
$$

Where 238.5 Ω is the edge impedance of the patch and y_0 is the distance from the edge that the transmission line or coaxial probe needs to be led to to match the impedances.

2.5 Polarization

Polarization explains how the electromagnetic waves are propagated through free space as a function of time. Linearly polarized waves can travel in either the vertical or horizontal planes while the circularly polarized waves can be pictured as rotating through all the planes when traveling in one direction.

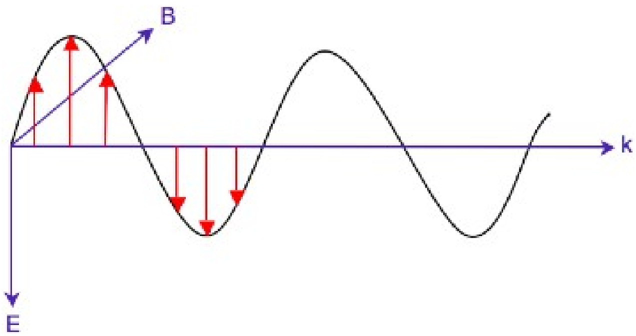

Figure 2.12: Linearly polarized waves

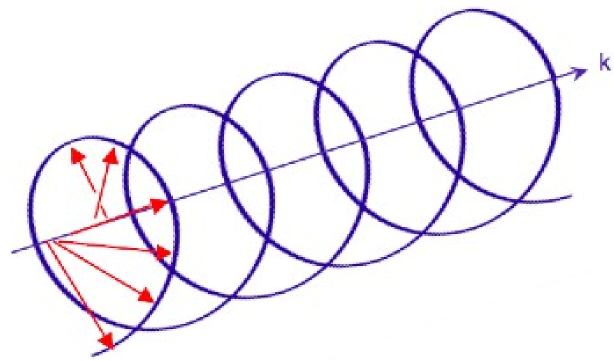

Figure 2.13: Circularly polarized waves

The common patch antenna will have linearly polarized waves and to cause a patch antenna to radiate in a circular pattern there exists a few methods that can be used. If the antenna is fed on two different points instead of one and the two signals have a 90 degree time-phase difference it will cause the patch to radiate orthogonal waves separately [3], these waves combine and become a circularly polarized wave. To create the 90 degree difference the signal is divided and one of the signals is then led along a microstrip line which have had the length of quarter of a wavelength added thus making it lag behind the other signal, shown in Figure 2.14. Another option for producing circular polarization without using two feed points is to feed the antenna at a corner instead of at an edge when feeding it with a microstrip line. This will cause two orthogonal transmitting modes to have a 90 degree phase difference as one mode will be 45 degrees ahead while the other will be 45 degrees behind and then creating a circularly polarized wave [3]. When truncating two diagonally placed corners of a square patch an asymmetry in the patch is created and the electromagnetic fields are altered to also allow for a different polarization [3][4].

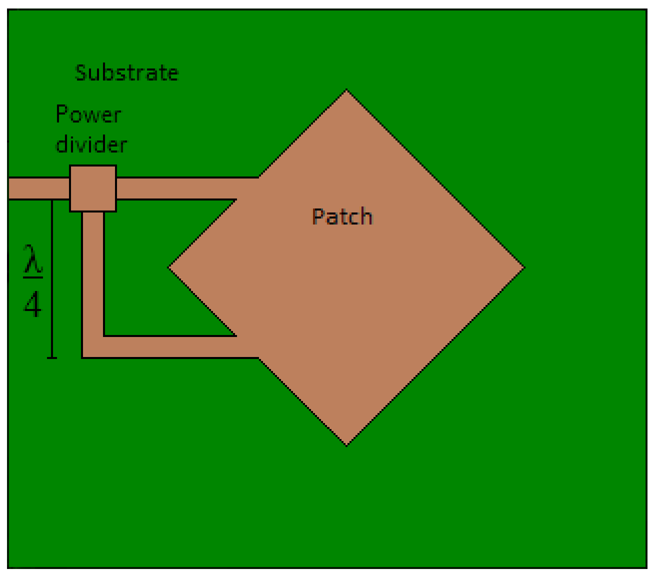

Figure 2.14: Patch antenna with circular polarization by dividing the signal

2.6 Gain and directivity

The term gain for an antenna explains how the radiation is propagated from the antenna. A low gain antenna will radiate in every direction causing the radiation field to resemble a sphere while a high gain antenna will direct most of its radiated power in one direction causing it to more and more resemble a beam the higher the gain is. The antenna gain is a comparison measurement with how much more power is received in the peak direction compared to that of an isotropic antenna and is measured in dBi, decibel isotropic. Directivity is very similar to the gain of an antenna but also includes the efficiency of the antenna to make it a more realistic figure of merit.

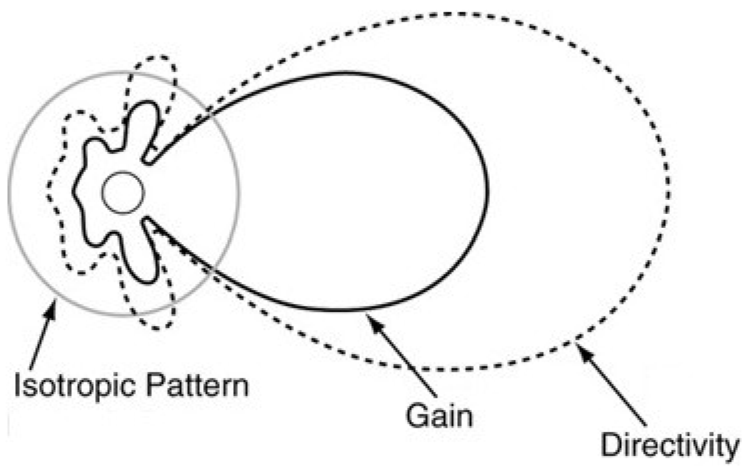

Figure 2.15: Similarities between gain and directivity

2.7 Bandwidth

Antenna bandwidth explains the frequency range in which the antenna operates properly. This is another important parameter to monitor when designing an antenna and it will need to correspond with the frequency requirements of the system. As mentioned patch antennas generally have a very narrow bandwidth and will not cause a problem for this system as the frequencies which commercial radio applications in Europe are allowed to broadcast in can easily fit within the bandwidth of the patch antenna.

3 Antenna Design

3.1 Project beginning

In the early stages of the project when research was done to see which antenna would be most suited for this system the attention were directed towards a special kind of radiating setup called leaky cable. A leaky cable is basically a regular coaxial cable with apertures, or holes, in the outer conductor so that radio signals escapes through these gaps so that each hole works as a little antenna.

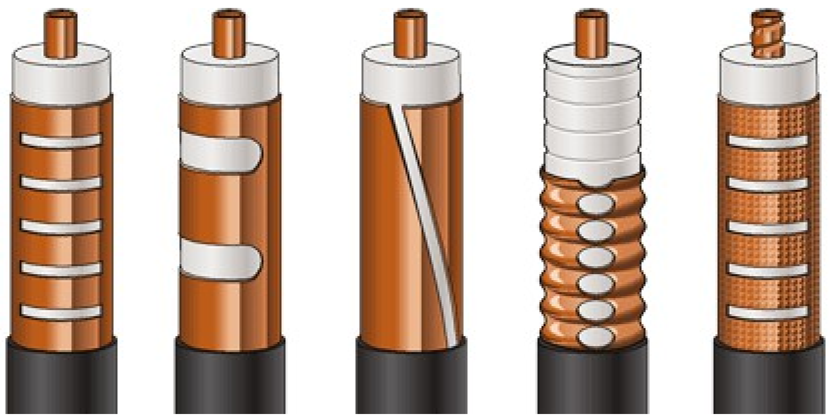

Figure 3.1: Different configurations for a Leaky Cable

Leaky cables are mostly used in underground mines or tunnels for radio communication because the cables can easily be installed in the ceiling to have good reception even deep down that an antenna transmitting from ground level would have a hard time achieving. When testing was being performed on the leaky cable the performance ended up being rather poor as the way the holes in the cable was designed caused the radiation to escape in several directions around the cable. The maximum power the available equipment could output was also not enough for the cable radiate enough and therefore the maximum read range that was measured using the leaky cable was something in the range of 5-10 centimeters which was far from enough for this system so other solutions was reviewed in favor for trying to improve the leaky cable.

3.2 The first design

As the plan for the antenna was to be mounted on the walls a low profile, high directivity antenna was desired. A patch antenna fit a lot of criteria of the system requirements and that antenna was chosen to be the main point of investigation of this project. The chosen method of construction was milling the antenna design out of a laminate as Syntronic conveniently had a milling machine available. To allow for a quick milling process the first antenna was designed with a minimum ground size [5], only just enough size to fit the fringing fields inside the substrate.

The available substrate that was used for constructing this antenna was a FR4 laminate made by Polyclad® with a dielectric constant ε_{eff} = 4.3, dimensions for the patch of the antenna was calculated using the formulas derived under 2.3.1 Transmission line model:

$$W = \frac{300}{2 \cdot 8.66} \cdot \sqrt{\frac{2}{4.3+1}} \approx 10.640$$

$$\varepsilon_{eff} = \frac{4.3+1}{2} + \frac{4.3+1}{2} \cdot \frac{1}{\sqrt{1+12\frac{0.08}{10.64}}} \approx 4.230$$

$$\Delta L = 0.412 \cdot 0.08 \cdot \frac{(4.23+0.3) \cdot (\frac{10.64}{0.08}+0.264)}{(4.23-0.258) \cdot (\frac{10.64}{0.08}+0.8)} \approx 0.037$$

$$L = L_{eff} - 2 \cdot \Delta L = \frac{\lambda}{2} - 2 \cdot 0.037 = \frac{300}{2 \cdot 8.66 \cdot \sqrt{4.23}} - 2 \cdot 0.037 \approx 8.348$$

The minimum sized ground plane was made by adding only 6*h to both the width and length of the patch, where h is the height of the substrate. Another advantage of using the inset-fed transmission line was that all that was missing from the antenna when the milling was done was to weld the connector to the end of the transmission line. The feed for impedance matching was designed to feed the antenna at a point on the patch where the impedance would be close to 50 Ω, which is a common impedance used in most cables.

A patch antenna can also be designed with 2 patches stacked on top of each other to further enhance some antenna properties. Since this project sought a low profile antenna this solution was completely disregarded. This initial small design was mainly made to investigate how a patch antenna would perform in real tests and compare it to a stock antenna that was bundled together with the RFID reader used. The design could then be evaluated and improved to create a better working antenna.

Shortly after the making of the first patch antenna the Ansys® HFSS simulation software became available which allowed the antenna to be analyzed in the software.

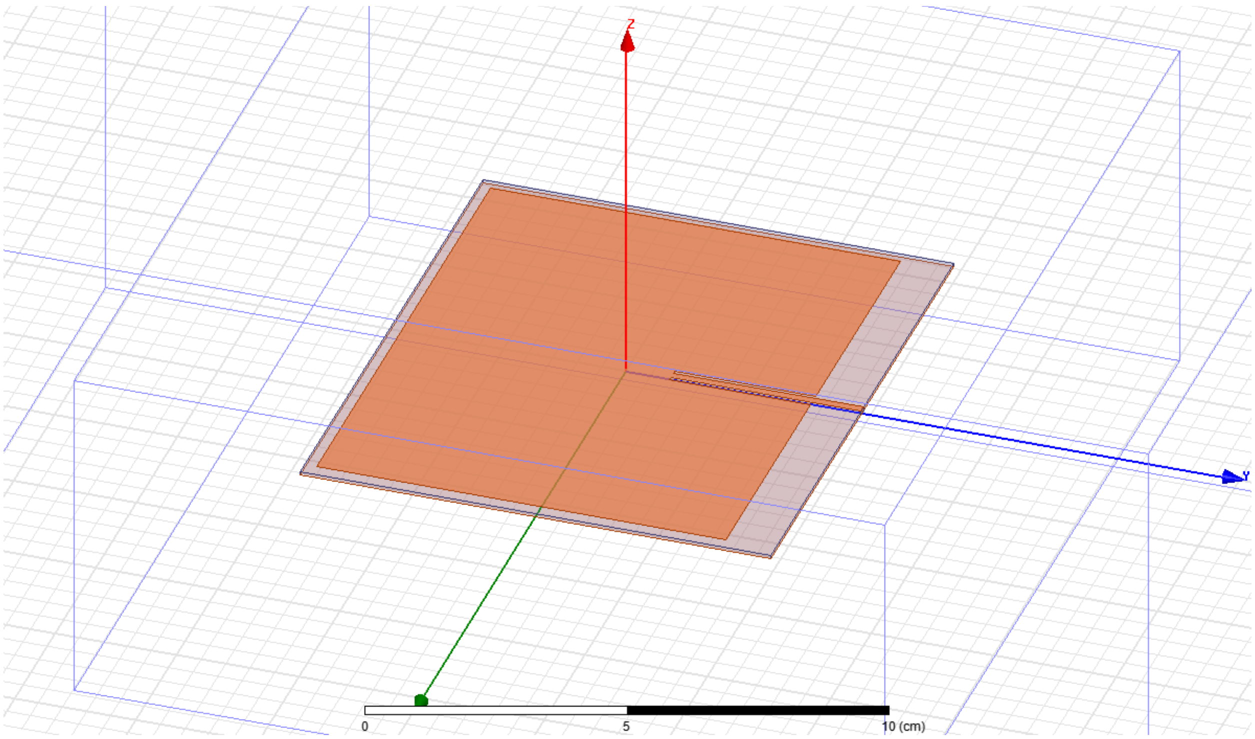

Figure 3.2: The first patch antenna created in HFSS

The gain simulations was the most interesting result the analysis of the first patch antenna produced. As seen in Figure 3.3 there is radiation propagated downwards most likely caused by the small ground plane as it can not prevent parts of the radiation escaping the edges of the ground plane and propagating in that direction, this causes the antenna to perform worse in the targeted direction.

In Figure 3.4 the smith diagram of the input impedance is shown, the curve on the smith char represents the reflection S11 plotted over the frequency sweep that the antenna analysis was done over. As expected the return loss shown in Figure 3.5 shows the antenna to have a very small bandwidth, but the graph also shows that the bandwidth is big enough for the antenna to broadcast adequately in the allowed frequency range. Most of the negative pulse in the plotted graph reside within the range 850-875 MHz.

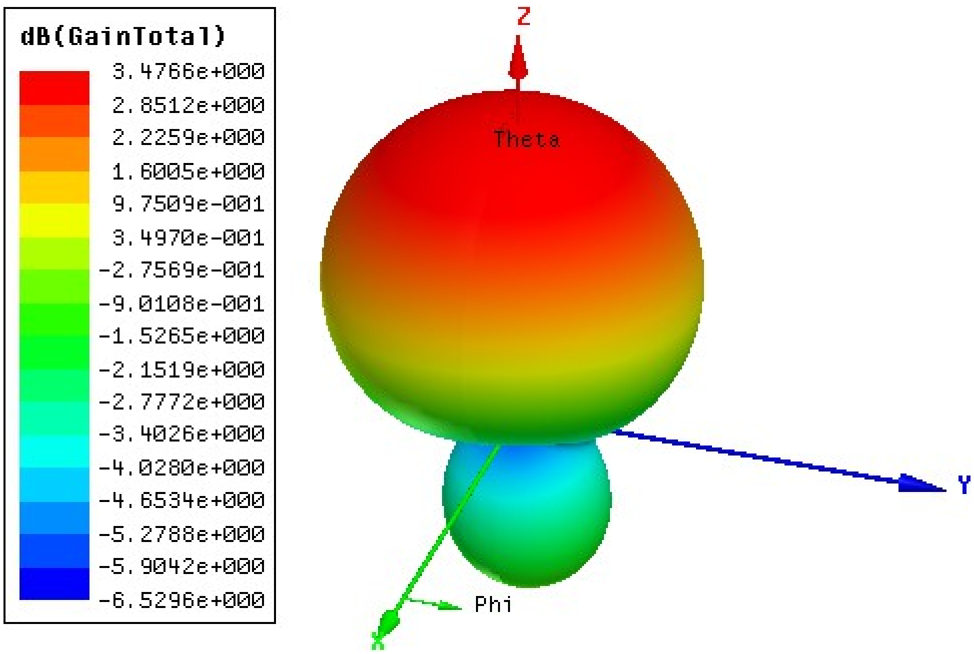

Figure 3.3: The simulated gain of the first patch antenna

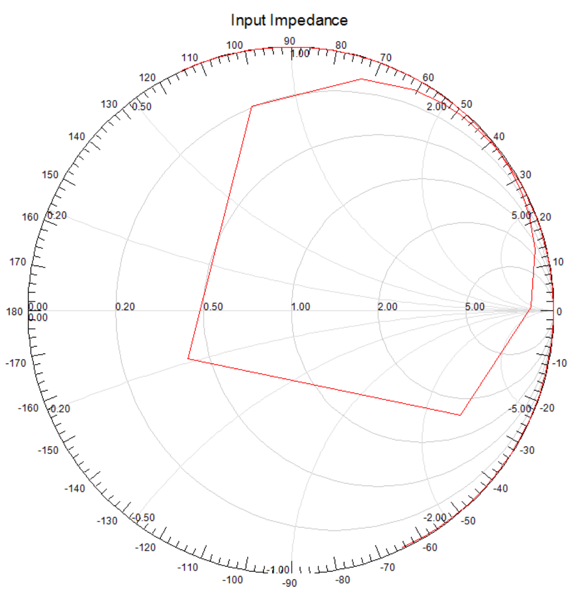

Figure 3.4: The simulated input impedance of the first patch antenna

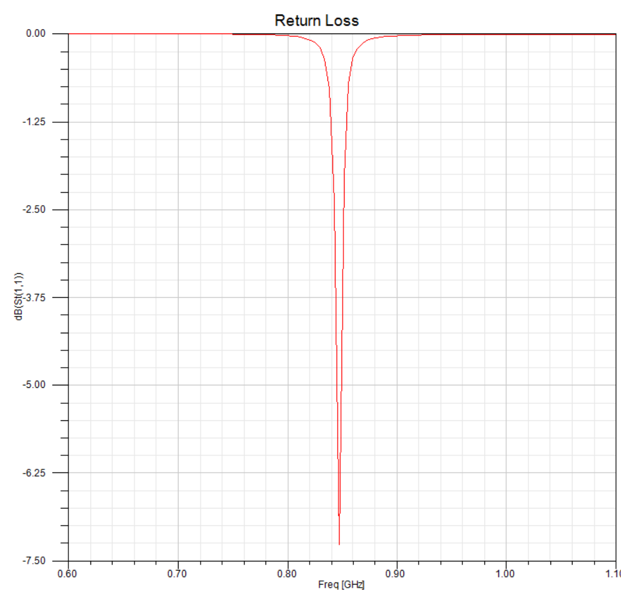

Figure 3.5: The simulated return loss of the first patch antenna

3.3 Improving the first design

Attempts to improve the poor read range the first antenna prototype had was done through simulating many different designs in HFSS. The main focus point was increasing the ground size to avoid having the antenna radiate in the wrong direction, therefore simulations was done on different ground plane sizes. A ground plane size that wouldn't take to long to complete was chosen, the time taken for this design to be milled out ended up being one hour as a bigger area around the patch needed to be removed on the top layer of the laminate, compared to around 20 minutes for the first design to complete. The ground size chosen here was a width of 17 centimeter and length of 14.5 centimeter and the model used for simulation in HFSS can be seen below.

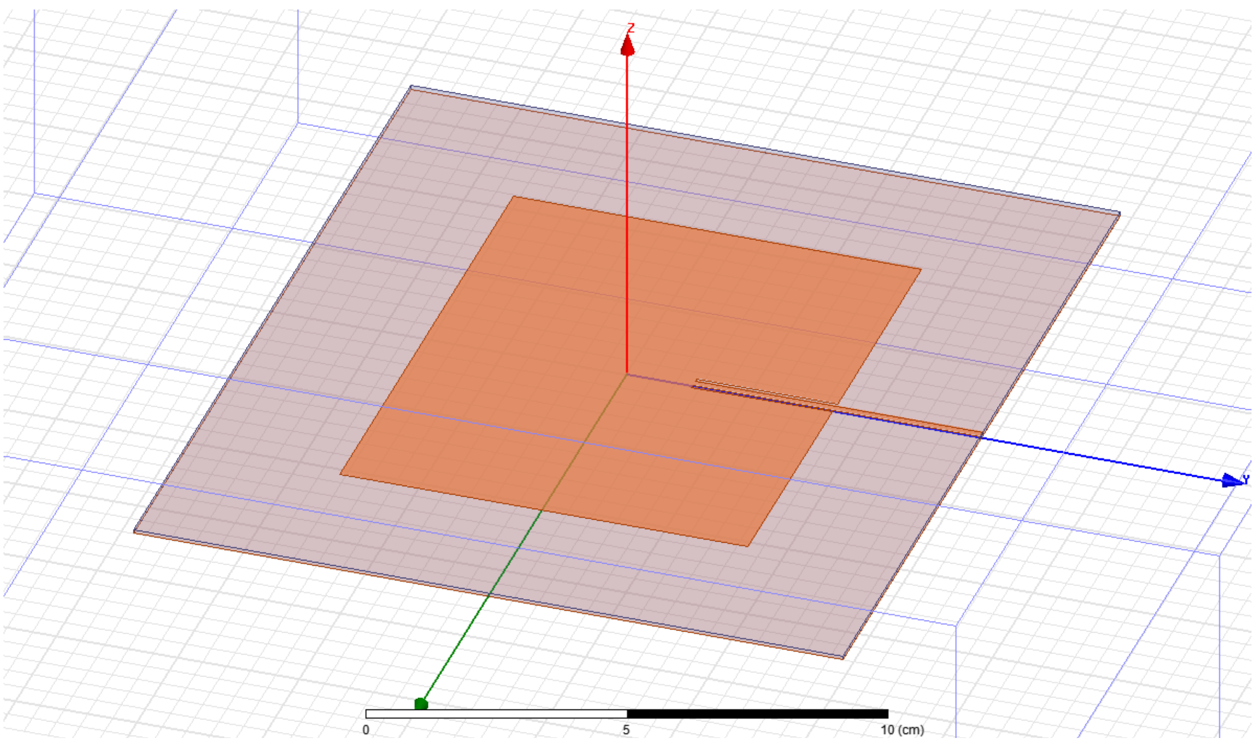

Figure 3.6: The second patch antenna created in HFSS

As seen in Figure 3.7 the maximum gain was improved by roughly ⅔ from the first design. This antenna ended up being the one used for testing in a RFID project example.

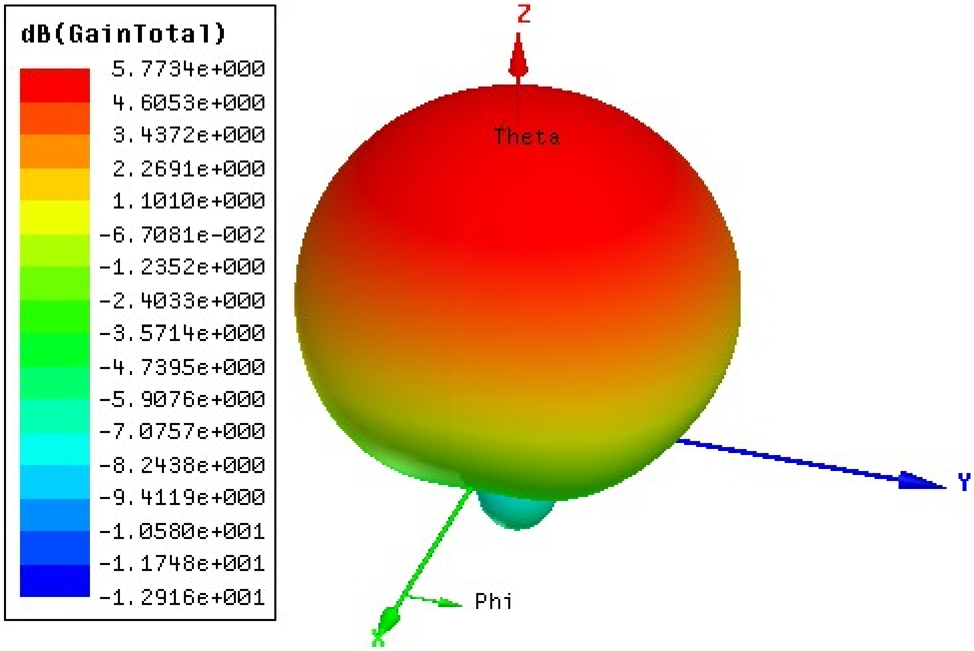

Figure 3.7: The simulated gain of the second patch antenna

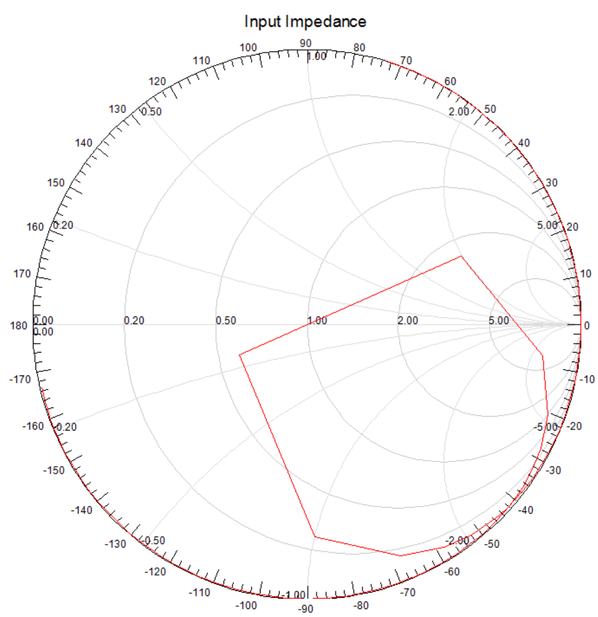

Figure 3.9: The simulated input impedance of the second patch antenna

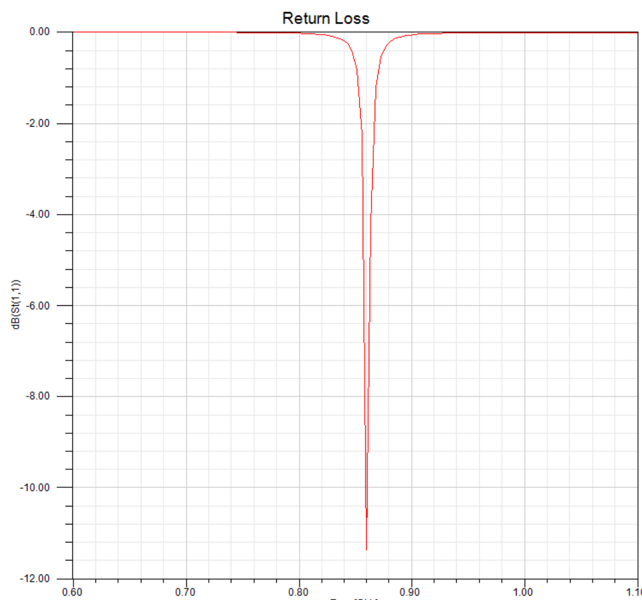

Figure 3.8: The simulated input impedance of the second patch antenna

3.4 Further Simulations

When the second antenna with a larger ground plane greatly improved the gain more simulations was done to see how much better the gain could be made. Simulations of different ground sizes was done to see how much the gain could be improved. This was done in HFSS where a design was made with a variable that modified the length of the ground and transmission line on the model, the width of the ground was fixed at 17 centimeter. The simulation could then provide a graph which showed the maximum gain of the different ground sizes, shown in Figure 3.11. The values of the variable gndlength on the x axis are the distance in centimeters between the patch edge and ground plane edge.

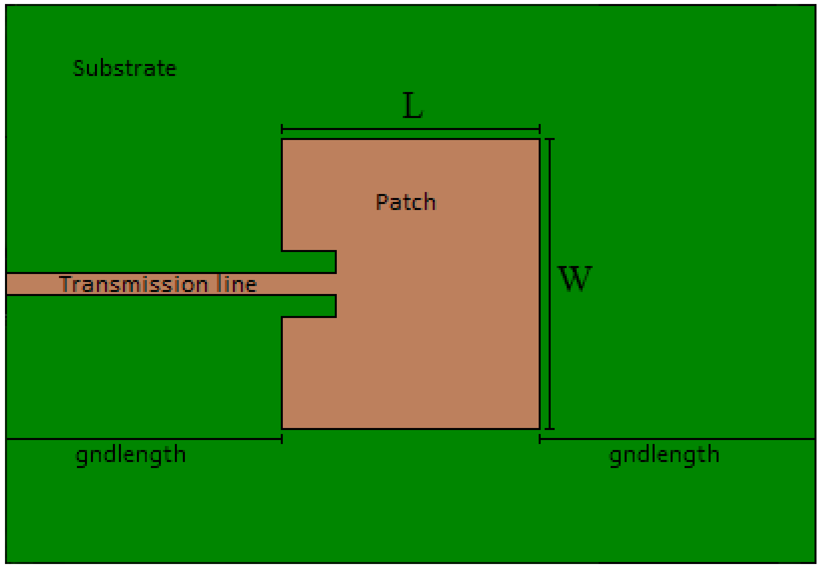

Figure 3.10: A patch antenna showing how the variable gndlength affected the simulations of the antenna

The second antenna design had a value of gndlength which would be close to 3 centimeters and that would put the gain close to the maximum that can be achieved for this type of design.

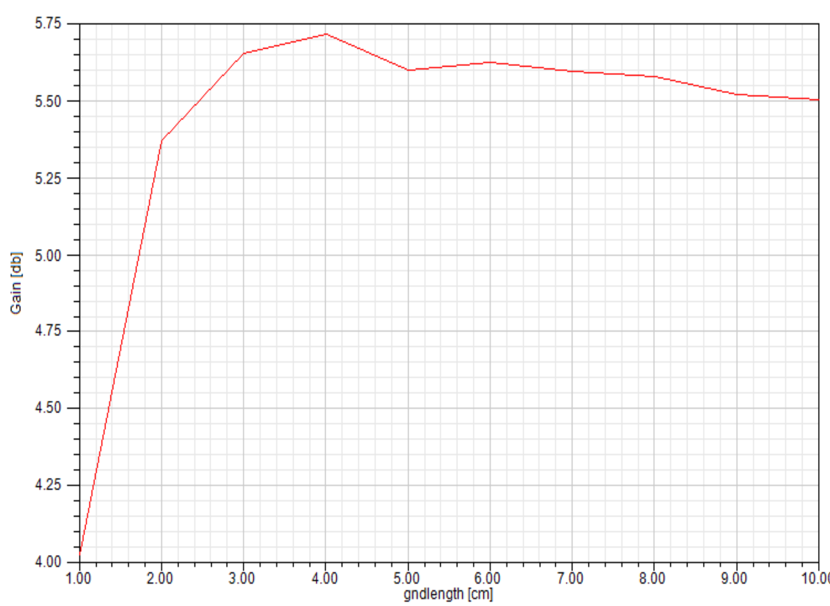

Figure 3.11: The simulation for comparing different sizes of the ground plane length

4 Measurements

4.1 Test environment

The antennas were tested with the ThingMagic® Mercury6 RFID Reader [6], which has a maximum transmit power of 31.5 dBm and is very convenient to use as it has a browser interface which can be used to monitor tag readings and status of connected antennas. The browser interface can also be used to quickly change settings in the read or write power for the antennas. The Mercury6 reader uses automatic detection on the antenna ports to know which ports have antennas connected to avoid transmitting on unused ports that could damage the reader, this scanning of the antenna ports are done when powering it up and also before transmitting. In order to be detectable a connected antenna must present a DC resistance of 10k Ω or less [6]. This DC resistance is available on the antenna that shipped together with the reader but not with the antenna that was constructed, after communicating with ThingMagic® support this was solved by adding an attenuator between the reader and the antenna which provided the necessary circuitry for the reader to detect a small DC resistance. This attenuator does of course affect the performance in a negative way but a small attenuator of 2 dB was chosen to try and minimize the attenuation of the signal.

A measurement antenna, Aaronia® HyperLOG 3080 [7], was used to verify that the antenna operated good enough within the European RFID frequency range 865-868 MHz. The reader was set to transmit on 4 different frequencies inside this range and an example of the values measured by the measurement antenna is shown in Figure 4.1. The peak values are the transmitted frequencies 865.7, 866.3, 866.9 and 867.5 MHz which are all equally spaced in the sub-band B for the allowed frequencies in Europe. These frequencies was used as sub-band B allows the most effective radiated power [1].

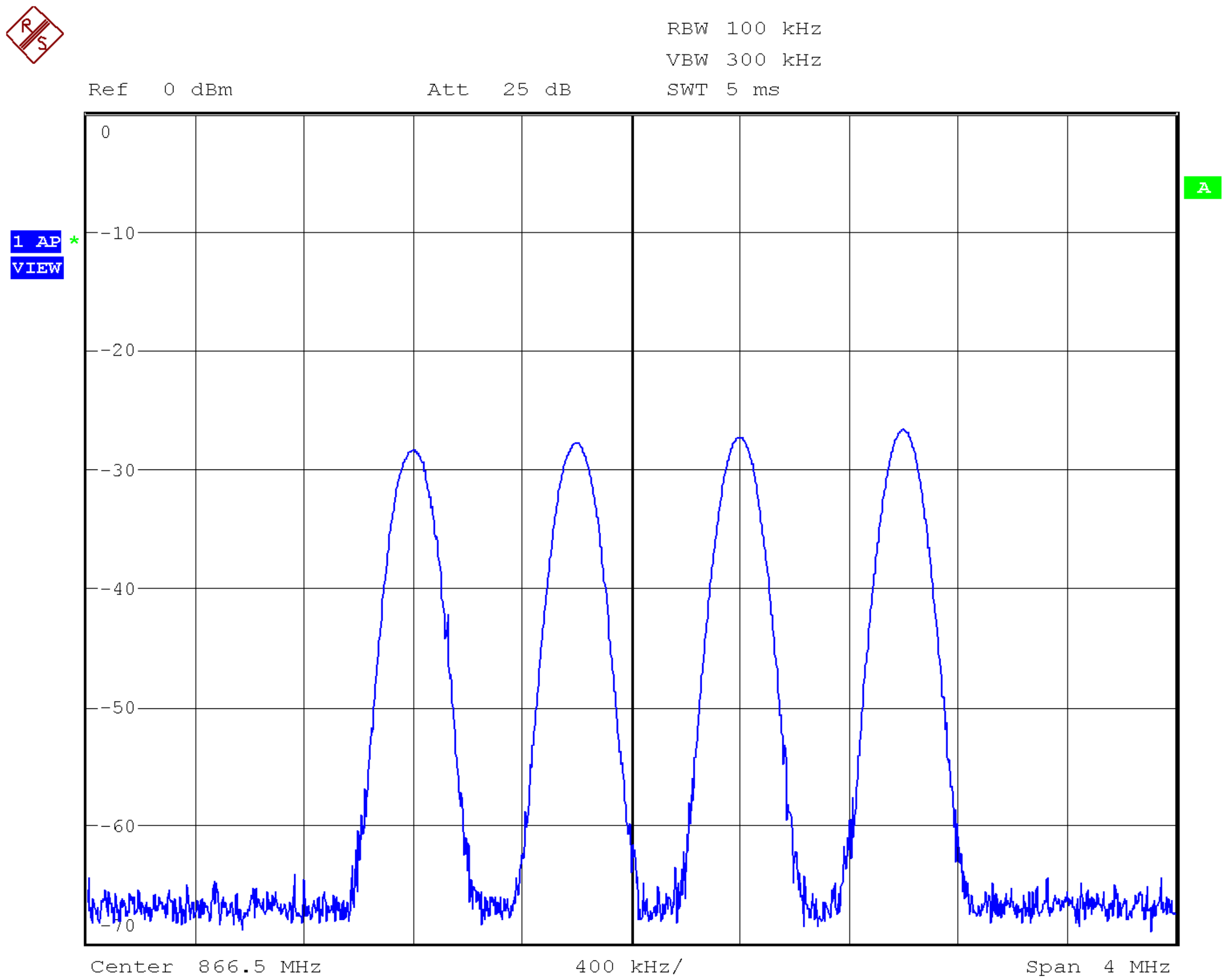

Figure 4.1: The resulting spectrum when testing Antenna 2

The room that these tests were performed in was a regular open space room, as no echo-free room was available. This room was wide enough to simulate how it could work in a wide corridor to satisfy this requirement of a future system. The tags that have been used most throughout the testing have been AD-827 [8] from Avery Dennison® which have the dimensions of 18 x 40 mm, these tags have an acceptable size if they were to be attached on for example the wrist of a human.

4.2 Antenna test 1: Maximum read distance

This test was done to see how well the antennas performed without any possible obstacles and minimal disturbance on the radio signal. The tags were placed on a cardboard box so that the distance from the antenna could easily be adjusted and to avoid having signal loss from other materials. The tag was then moved around to where the reader just detected the RFID tag and noted down. The measured maximum read range of the first patch antenna was 60 centimeter and 110 centimeter for the second patch antenna.

The simulated ⅔ gain improvement between first and second patch antenna was confirmed with this measurement here as the read distance was close to doubled with the second antenna.

4.3 Antenna test 2: On-human read distance

As the first patch antenna did not even have the acceptable read range in the test 1, only the second patch antenna was used when testing the antenna with the tag on the wrist. The tag was placed on top of a 1 centimeter foam which was held on the wrist with a rubber band. This 1 centimeter spacing is necessary to allow the tag to at least be detectable.

With the tag attached directly on the skin the RFID tag was not detectable until it was held only 5 cm from the antenna so the tag need at least the 1 cm distance from the body to get a reasonably good result. The tag was also placed by the side of a big plastic can filled with water to simulate the body while also put on a plastic stand that held the tag 3 cm from the water to see the read range.

Tag placement	Read range
On skin	5 centimeter
With a 1 centimeter foam spacer on the human wrist	40 centimeter
With 3 cm plastic stand spacer on a water filled plastic can	110 centimeter
On cardboard (test 1)	110 centimeter

As can be seen the performance diminishes drastically the closer the tag is to water.

5 Discussion

When trying to make a low profile antenna which had acceptable results in terms of read range the second patch antenna have a read range of 40 centimeter when tested with the tag spaced 1 centimeter from the body which is realistically how the tag would have to be placed in a real environment. The gain of the second design could have been improved slightly more with adding a ground plane which was a little bigger.

The big negative part of using this patch antenna design is that the polarization of the antenna is linear, this means the tags have to match the orientation of the antenna to be able to be detected at longer distances then 10 centimeter. In a real environment with tags worn by humans it is impossible to guarantee that the tag will be aligned perfectly hence the polarization have to be improved if this kind of antenna is to be used.

Comparing the measured results to an active RFID solution it would be preferred to choose the active RFID system as that would have no problem performing adequately in this kind of environment and setup. The problem with using active RFID is that the tags which is to be worn on humans cost a lot more than the passive tags because of the battery and its casing. The battery will eventually have to be replaced as well, with risks of affecting the performance negatively when the tags battery charge is getting low.

The shelf antenna that was delivered with the RFID reader performed quite well during some tests which means there is no reason to think a passive solution would not be fit for this system. Using this antenna would of course be an option but installing it to cover a whole building would not be very cost effective and therefore not preferable. If the patch antenna design could be improved further the cost to manufacture and install them to cover a big building would be significantly less then using the passive shelf antenna or the active RFID setup.

The substrate which has been used throughout this project was probably not the most optimal either and would have to be changed when trying to improve this design. The specifications used for the substrate was not entirely clear and this called for assumptions to be made which would have impacted the antenna negatively if they were wrong.

5.1 Limitations

The second patch antenna have a few small tweaks that can be made to slightly improve the gain of that antenna.

- **Impedance match**

  Since an error was made in the calculations for the impedance matching the impedance at the feed point is approximately 52.5 Ω instead of 50 Ω and there is therefore a slight mismatch which will cause a little bit of reflection. The correct value to use for the inset to match against a 50 Ω source impedance is acquired by using L = 8.346 in the calculations instead of L = 8.246 which is where the error was made. This gives $y_o \approx 2.91$ centimeter instead of $y_o \approx 2.875$ centimeter which is what was now used in the manufactured and tested antennas. The milling machine gives an accuracy 0.2 millimeter so correcting this would have been possible if not discovered to late.

- **Attenuator**

  With the attenuator attached between the antenna and reader the signals sent to the antenna will already be attenuated before even being transmitted through the air. Using the antenna with a reader that does not require the use of an attenuator is preferred but none of the other available RFID readers provided a big enough transmit power to perform better then the Mercury6 and the attenuator attached.

- **Ground size**

  As was shown under chapter 3.4 Further Simulations the ground plane could have been further expanded to give a slight gain increase.

If the three points above are changed this antenna will have good performance but only with specific tag alignments, to fix this there are a couple of changes that can be made to further improve this patch antenna.

5.2 Future work

Constructing a new antenna with circular polarization is the single most important task to be performed to have the antenna fit this system better. Adding circular polarization do however introduce a problem, the read range of the tags will be cut roughly in half. Since the tags are linearly polarized they can only receive the part of the wave that is in phase and with the circular polarization being two orthogonally linearly polarized waves 90 degrees out of phase only one of these waves will be picked up by the tag [9]. The tag would however be able to be rotated in any way possible without affecting the read range with this polarization, this would put responsibility on the system rather then demanding that the users correctly align the tags towards the antenna which would not have been a reasonable solution in this environment.

To improve the gain after circular polarization has been accomplished the antenna can be constructed as an array of patches, this only makes the antenna dimensions bigger but it still keeps its low profile. By making an array of these antennas the antenna specifications could be improved much further [10][11], which would be a needed step to take if circular polarization is introduced to produce an antenna with a more satisfactory result. By placing the patches as an array the gain could be increased by as much as 5 db with using a 1x4 patch antenna array [12] and greatly improve the read range of the RFID system to a good level.

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