WALKING POWER SOURCE: USING YOUR JACKET TO WIRELESSLY HARVEST POWER

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STATEMENT OF CANDIDATE

I, (Chenxing Li), declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering in the school of Engineering in electronic engineering in Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment an any academic institution.

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ABSTRACT

Capturing and harvesting RF energy, using small antenna with an effective conversion RF energy into DC voltage with minimal losses would be significant problem in modern world.The purpose of the project is design a antenna system which is can operated at 5GHz ISM band used to collect the RF signals from ambient environment which is can be converted in DC power.The project would be end up with emboridery antenna, which can stitch on fibre, be able to collecting RF signals from ambient environment, and also this antenna should be operated under 5GHz, Wi-Fi operation frequency.This overall project focused on the emboridery antenna design, and the project can be divided into many sub-systems.Firstly, since we got prototype of the simple microstrip patch antenna and get simulation result that we aiming to, then can start fabricated a real microstrip patch antenna. The embroidery antenna designing is based on the siple microstrip patch antenna which is can collect RF signals from ambient environment then used to convert the RF signals into DC power.

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Chapter 1

Introduction

Capturing and harvesting Radio-Frequency (RF) energy, using small antennas with an effective conversion of RF energy to Direct Current (DC) energy with minimal losses presents a signi

cant research problem. In todays consumer driven, fast paced, continually changing and technically advanced environment there is a signiffcant dependency on battery based wireless devices. Also, within this environment there are numerous other wireless devices such as Wi-Fi transmitters and RFID scanners, radiating signifcant amounts of excess RF energy which is wasted and unused. The compatct size, low rigidity or more flexibale, low power consumption antenna can be used in many ways, like enhance communication signals, or tracking patient's symptoms, or even communicated between space-station or satellite.This type antenna should be operated under WiFi frequency 2.45GHz or 5GHz. This peoject is require to design a part component of rect-antenna system, the main focus of the project is going to create the embroidery antenna part of the wearable rectanna system, the embroidery antenna is going to collect the RF signals which is used as input for the rectifyer circuit, that can convert the RF signals into DC power. and also becaused the rectanna system is required as wireless rectanna system, the embroidery antenna need to be operated under 5GHz WiFi operation frequency. The embroidery antenna should he have the following propertiey

- The bandwidth of the antenna should be wide bandwidth, which is allows many different frequencies operation.
- The antenna should have high efficiency that can collect the RF signals from ambient environment in effective ways
- The size for the antenna should be compact, and more flexiable, that can be implemented in comnercial way.

In this report will discussed the works done to achieved the antenna, and the simulation prototype in detial and also the simulation results. Since finised the simulation part, the work can switched to fabrication part and also need to do the physical testing.

Since got the physical testing result and simulation result, will compared those two type of result, and discussed the result obtained from those two part.

1.1 Overview of The Project

For achieving the project should be divided the whole project into sub-system for the whole object. This section will overview the overall for the porject, the overall project is going to created a embroidery antenna which is used to collect the RF signals from ambient environment that can be used to convert the RF signals into DC signal. For achieving the project, break the overall object into subsystem, the sub-system should be following:

- Design simple microstrip patch antenna can operated under Wi-Fi frenquency at 5GHz.
- Improve the microstrip patch antenna's bandwidth
- Fabricated the emboridery antenna.
- Physical testing for the emboridery antenna, testing the reflection coefficient of the antenna
- Compared and discussed the result obtained in both simulation result and physical testing result, discussed the improvement and lose for ideal condition which is simulation and in realistic condition for the performance of the antenna.

For this report will discussed the progress for this project. In the chapter 2 will go through the background theory which are supporting this project designing in different area, the consideration for designing the simple microstrip patch antenna in detial, discusses the recitifying circuit,since the rectifying circuit designing is not the main purpose for this project, therefore in the chapter 2 will general discusses this subsection, the last subsection would be the embroidery antenna consideration. The chapter 3 will discusses the prototype of the microstrip patch antenna, in this chapter will discusses the software used in this design, is called the CST Microwave Studio, will discussed the procedures in prototyping the simple microstrip patch antenna, and the parameter may affected the performance, and how to improve the designing. The following chapter which is chapter 4 will simulate the bandwidth for this prototype and discusses the design parameter for this microstrip patch atenna. The chapter 5 will go through the fabrication part of the antenna,will state the procedure and equipment setting and consideration for fabricated embroidery antenna and do the physical testing, testing the bandwidth for the antenna,then compare the simulation results with physical testing result, state the difference between those two result which are obtaining from simulation and physical testing and also discusses the potential reason why the difference happened. The lase chapter is conclusion and future work. In the conclusion, will states the final embroidery antenna has been successfully created,which is means the physical performance for this antenna has reasonable bandwidth, but will states the future works for the antenna in both long term and short term,

Chapter 2

Background Theory

This section is going to discusses the theroy behind this project, the first subsection is about the design parameter about simple retangular microstrip patch antenna, and some parameters which are used to indicated the performance of the antenna. The second subsection is about rectifying circuit, due to the rectifying circuit is not the main purpose of the project, therefore this subsection will not go through in detail. The last subsection will discusses the embroidery antenna theory, which is also supporting this project.

2.1 Microstip Patch Antenna

A microstrip patch antenna structure contains of a thin layer of low-loss insulating material called the dielectric substrate. The microstrip patch antenna is composed by ground plane, substrate and patch.The thin metal strip $t << \lambda_0$ t is placed small fraction of wavelength above the ground. the thichness for the metal, and the λ_0 is the free space wavelength,For rectangular patch antenna the L, which is the length of the patch is usually between $\lambda_0/3 \leq L \leq \lambda_0/2$, the ground and patch is separated by dielectric layer which is called substration.
For the substrate, there are many choices.Usually, the substrate should be between $2.2 \leq \epsilon_r \leq 12$. between the ground and patch as figure. 2.1
For obtain good antenna performance,it should be designed by thick substrate high and small dielectric constant, this would resulted in high efficiency, wide bandwidth and lossely bound fields for radiation into space.For the high dielectric constant and thin substrate has following properties, tightly bound fields to minimize undesired radiation and coupling,and also gives a more compact size compare to the thick one, because of those properties, those type design would better for microwave circutry.The reason it called "patch" antenna, because usually the radiating element and the feed element are photoetched on the surface of the substrate. There are many shape for the patch, it could be rectangular, elliptical, circle, triangular and so on. The most common would be rectangular, for this project, the emboridery antenna would mock up by rectangular microstrip patch antenna.

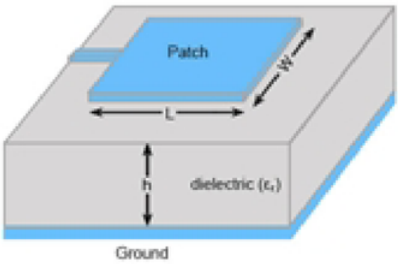

Figure 2.1: Microstrip Patch Antenna

The main advantages of microstrip patch antennas when compared to conventional an- tennas, include be included following:

- They are lightweight, compact and are small in volume and profile;
- They have a low fabrication cost and can be easily mass manufactured and produced;
- They can be effortlessly integrated and combined with microwave integrated circuits(MIC);
- They allow linear and circular polarisation;
- Feedlines and matching circuits can be easily manufactured in conjunction with the antenna patch;
- They can easily allow for dual frequency operation.

The main disadvantages of microstrip patch antennas when compared to conventional antennas, include the following:

- They have a narrow bandwidth;
- They have a lower gain and reduced effciency;
- Low power handling capabilities;
- Extraneous radiation from feeds and junctions;
- Excitation of surface waves

2.1.1 Dimension for the Microstrip Patch Antenna

The square, rectangular as shown before in Figures 2.1,are the most commonly used antenna geometries for microstrip antennas.
One of the most important design considerations to be considered when designing a square or rectangular microstrip patch antenna are the dimension parameters. The main dimension parameters which can of the diagram include; Length(L), Width(W) and Height(h). The Thickness (t) of the radiating antenna patch and the ground plane is not really critical in the design of a microstrip antenna; however, it should have a sufficient thickness, usually three times the skin depth or not smaller than 0.025 of the wavelength or the antenna effciency will be degraded.
The approximate length (L) of a resonant half-wavelength patch is given by equation where λ is the free space wavelength and ϵ_r is the dielectric constant of the substrate. The length of the antenna patch is a highly important parameter as it controls the resonant frequency. It must be noted that the length of a half-wave patch is to some extent smaller than half a wavelength in the dielectric substrate. Also this length is an approximate and hence empirical

fine tuning is needed in real life to get the correct resonant frequency

$$L \approx 0.49 \times \frac{\lambda}{\sqrt{\epsilon_r}} \tag{2.1}$$

The width(W) for a square patch geometry is equal to the length as given in following equation. However, for a rectangular patch geometry where the width varies from the length, a larger antenna patch width increases the power radiated and hence this results in decreased resonant resistance, increased bandwidth and increased radiation effciency . An approximate width of an antenna patch is given by equation 2.2; where c is the speed of light and f0 is the frequency. Since this is an approximate, empirical

fine tuning is needed in real life to get the optimal width [4]. It also must be noted that the width of the patch also has a slight effect on the resonant frequency and the radiation pattern . The equation is fllowing:

$$W \approx \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \tag{2.2}$$

The thickness or height (H) of the dielectric substrate material is another important factor when designing a microstrip patch antenna. A thick substrate; would be resulted in increasing the radiated power, a reduction in conductor loss and an improve the bandwidth. However, some drawback will happen when using thich substrate like increasing in weight, dielectric loss, surface wave loss, and extraneous radiations from the probe feed . Also the substrate selecting will depands on the stock as well.

2.1.2 Substrate Properties

The dielectric substrate is a key component of a microstrip antenna, it plays an important role both electrically and mechanically. Electrically it is crucial for transmission lines, circuits and the antenna patch. The key electrical properties include the relative permittivityϵ_r, and the dielectric loss factor tanδ. The thickness of the substrate is also a key property and has been discussed thoroughly in the previous section.Generally, for microstrip antennas a substrate that has a low valued permittivity constant, increases and enhances fringing

elds at the patch perimeter and hence increases the radiated power. Also the value of permittivity determines the size of the microstrip patch antenna, with a higher permittivity resulting in a reduction in size. However, it must be noted that for microwave circuits (such as a rectifying circuit section from a rectenna) attenuation occurs in the microstrip transmission lines. This attenuation is caused by; dielectric loss, conductor loss and radiation loss. Hence to reduce the atten- uation, a substrate material that has a high permittivity constant should be selected as it reduces the radiation, the dielectric loss and also results in a reduction in size of the microwave circuit, which thus extends the performance of the substrate at higher frequencies . The dielectric loss factor is another important parameter in relation to substrates. To achieve a highly effcient antenna, high circuit performance and overall effciency; a substrate with a low dielectric loss factor should be used. Typically it should be smaller than tan $\delta = 0.002$.
The key mechanical properties of a substrate which may or may not be crucial depending on the application, include the: mechanical resistance, shape stability, expansion factor and temperature threshold .The main categories of dielectric substrate materials include: ceramic, semi-conductor, ferromagnetic, synthetic and composite.

2.1.3 Feeding Method

The two main and most common feeding techniques used in microstrip patch antennas are; the coaxial probe feed technique and the microstrip transmission line feed technique. For the coaxial probe feed technique, the coaxial line is set perpendicular to the ground plane, and the centre conductor is connected to the patch which then extends across the dielectric substrate . A diagram of the coaxial probe feed can be seen in Figure 2.2. The main advantages of the coaxial probe feeding technique is that it can be easily located at any position on the patch so that it can be matched with the input impedance. The main disadvantage is that the substrate has to have a hole drilled through it, something that should be avoided, and hence since the connector will protrude outside the bottom of the ground plane, the structure would be no longer planar. The following figure shows this feeding method.

The microstrip transmission line feeding technique is the simplest way to feed a microstrip patch antenna, for this technique the transmission line is directly connected to the edge of the antenna patch. A diagram of the microstrip transmission line feed can be seen previously in Figure 2.1.The main advantage of this is that the transmission line is etched on the same substrate as the patch and hence it remains planar. The disadvantage is the radiation from the transmission line can lead to an increase in the cross-polar level. However, it must be noted that there are disadvantages for both these techniques when a thicker substrate is used. For the coaxial probe feed, an increased probe length due to

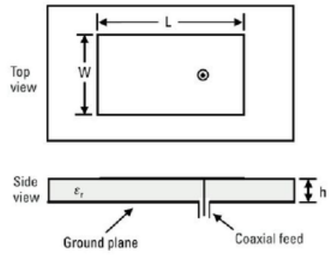

Figure 2.2: Microstrip Antenna Coaxial Probe Feed

substrate thickness causes the input impedance to be more inductive, which thus leads to matching problems. Whilst on the other hand for the microstrip transmission line feed an increase in substrate thickness would intern increase the width of the transmission line and thus leads to undesired feed radiation.

2.1.4 Improvement Bandwidth

For improve bandwidth of the microstrip patch antenna, there are two methods for solving this problem.
One of the most common way would be increasing the width of the rectangular microstrip patch antenna a larger antenna patch width will increases the radiating power and change the radiating pattern and hence this would be decreased resonant resistance, increased bandwidth and increased radiation effciency.
Another method to enhanced the bandwidth would be increase the thickness of the substrate since the bandwidth of the microstrip patch antenna is directly proportional to the substrate thickness. However, increasing the thickness of the substrate is counterproductive because of the occurrence of surface waves, but if a lower substrate permittivity is used in conjunction with the thicker substrate it is possible to prevent surface waves and hence enhance the bandwidth
Some other methods and techniques for improving the bandwidth of microstrip patch antennas such as increasing the inductance of the microstrip patch by cutting holes or slots, and by adding reactive components to reduce the Voltage Standing Wave Ratio (VSWR). It has also been suggested that using a high dielectric substrate to decrease the physical dimensions of the plate line would also enhance the bandwidth [8]

A factor which has an effect on bandwidth but not widely reported, is the dielectric loss factor tanδ. An increase in dielectric loss factor tanδ decreases the impedance variation and increases the loss in the patch, thus leading to an increase in bandwidth and a decrease in effciency. The main reason for this increase of bandwidth is because of an increase in the dielectric losses in the substrate. Hence a higher dielectric loss factor tanδ substrate gives an enhancement in bandwidth but with a negative impact on effciency and gain.

2.1.5 Fringing Effect

The dimension for the transmission line is finite, the radiation fields undergo fringing for the edge of the radiating patch, for both of length and width, therefore the electrical dimension is large compare to the physical dimension. The amount of the fringing is the function of the physical dimension of the patch and height of the substrate.Basically, is the ratio of the length (L) of the patch over the height of the substrate(L/h), if the ratio is small ($L/h << 1$) the fringing is reduce, this is important because it will affect the resonant frequency of the antenna.

2.1.6 Effective Dielectric Constant

There is another important design factor would be involved in this designing project, is called effective dielectric constant ϵ_{reff}.For the typical electric field line is shown above as 2.3 It is non-homogeneous line for two dielectics, substrate and air, from the figure 2.3

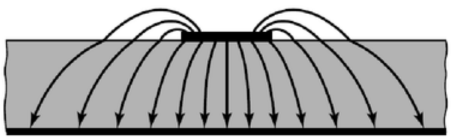

Figure 2.3: Electic Field Line

can see most of the electric field line reside of the substrate, and some of the electric field lines exist in the air. For the situation when $W/h >> 1$ and the substrate within $\epsilon_r >> 1$ the electric field lines would be concentrated in substrate, this would be makes the electrical dimension is wider than physical dimension, because of the electric field line can be transmit both in the substrate and air, the effective dielectric constant would be used for fringing and wave propogation in the line.Usually, for the electric field line with the air above the substrate, the ϵ_{reff} shoule be between the $1 < \epsilon_{reff} < \epsilon_r$, for the most case, the dielectric constant should be large than 1, that would be resulted in effective dielectric constant would more close to dielectric constant of the substrate, and also the effective dielectric constant is function of frequency as well, as the operation frquency increase, more electric fild line would be concentrated in the substrate, then the microstrip line will like a homogeneous line with substrate, ϵ_{reff} would be approach to ϵ_r of the substrate.At the beginning, for the low frequency, the constant is essentially constant, as the frequency increasing to the intermediate, the constant increasing monotonically, and finally reached to dielectric constant of the substrate.

2.2 Rectifying Circuit

The rectifying circuit is not the main purpose for this project, but the rectifying circuit is also really important part for the rectanna system.The rectifying circuit is going to convert the RF signals into DC power, which is obtained from the antenna.
The rectifying circuit is not the main purpose of the project, but will implemented in the overall rectanna system. Since the antenna has been created, can connect the input of rectifying circuit with output of the embroidery antenna, this is rectanna system, is used to collect the RF signals and convert into DC signals. The energy can be obtained from ambient environment, such as the movement of the door,

Rectifying circuit is used to convert AC signals into DC voltage, usually, it contributted by diodes and capacitors.There are two common types of rectifying circuit, half-wave rectifier and full-wave rectifier.The half-wave rectifier only allowed passes the half-circuit of sinusoid signal, then convert into DC voltage; the full-wave rectifier allows pass through the full sinusoid wave signal, then convert into DC voltage.
The half-wave rectifier circuit usually used in low power applications, because the output amplitude is lower than input amplitude, the negative wave of the AC signals would be blocked by the circuit, the half of input is unused, and also this circuit would be resulted in many ripple voltage that hard to filtered out.
In order to get the higher output voltage compared to the half-wave rectifier circuit,and less ripple voltage should be full-wave rectifier circuit, and the most common configuration of the full-wave recifier circuit would Full Wave Bridge Rectifier circuit.

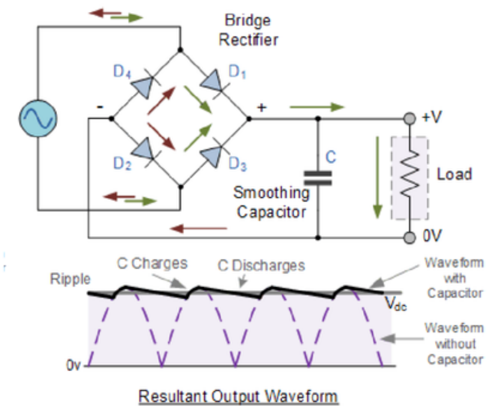

Figure 2.4: Full Wave Bridge Rectifier Circuit

2.2.1 Two cell Dickson Charge Pump Voltage Doubler Rectifier

This type of rectifier circuit is demonstrated in 2010, it was fabricated on 50 mil thick low-loss substrate material, the schmetic of the circuit like: There are two zero-bias RF

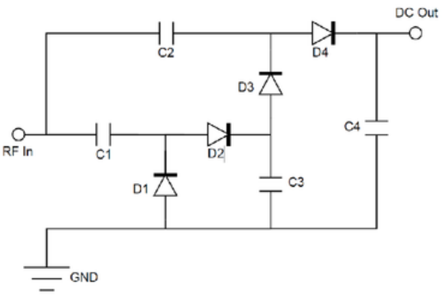

Figure 2.5: Two cell Dickson charge pump voltage doubler rectifier

Schottky diode pairs implemented in this circuit. These diodes do not require external biasing, and they have how barrier and high saturation current, those features would be resulted in high voltage output at low power level, but this circuit has high resistance loss because of the high resistant series.The capacitors C1 and C2 in the circuit prevent DC current from flowing between the input RF port and the diodes and the capacitors, C3 and C4store the resulting charge to smooth the output voltage.This circuit can produce DC output voltage which is four times peak voltage of RF input, and the efficiency equals to 60%-70%

2.2.2 Greinacher Rectifier

Another type of rectifier circuit would be Greinacher rectifier, this efficiency of the circuit design is critical for power harvesting,this circuit would provide more efficiency conversion.The circuit diagram is below: In the circuit D1, D2, D3 and D4 are four zero-biasing

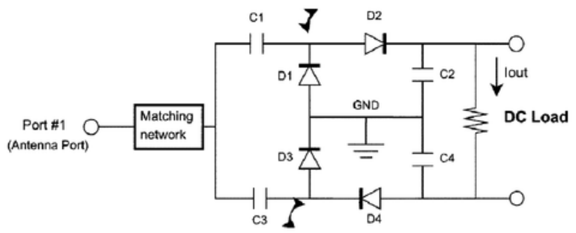

Figure 2.6: Greinacher Rectifier

low-barrier Schottky diodes of the rectifier, implying higher output voltage even though the RF power is at low power levels. Those diodes do not require additional biasing,This rectifier circuit would work like this;First, the induced voltage at the output of the matching circuit passes through the DC blocking capacitors (C1 and C3). The recti

ed current output is then pumped to the storage capacitors (C2 and C4). The energy stored on these capacitors supply the DC power to the load, once the rectifier reaches its steady-state mode This rectifyingcircuit has further improved sensitivity and effciency compared to other rectifying circuits.
Because this circuit would gives more efficiency, and higher output voltage in low power level, this circuit would be used in this porject.
For this rect-antenna could be work properly, the impedance of the circuit sould be matching to the impedance of the antenna, in order to get good performance for the rect-antenna system.

2.3 Emboridery Antenna

For fabricated textile antenna design, the wearable antenna requires mechnical flexiablity,low weight and reliability in terms of electrical performance. Basically, the manufacturing techniques could be devided into two groups:

1. Uniform, thin metallization layers (i.e. copper tape) fixed on the non-conductive textile fabric
2. The use of conductive textile yarns to weave, knit or embroider the conductive pattern of the circuit (i.e. patch antenna or transmission line) on the textile fabric

the substrate for wearable antenna could be cotton, and copper conductors should be used to fabricated wearable antenna,but this method has limitation in rigidization effect because of multi-layer assembly.The most common method for manufacturing emboidery antenna could be used computer-aided embroidery of conductive yarn on textile substrate.

There are few type of conductive yarn would be implemented in design embroidery antenna. Average diameter of 0.4mm and weight 240 dTex it is provided by *Ohamtex*. Each yarn consists of 48 polyester (PES) filaments and one or two silver plated copper filaments with diameter equal to 40μm or 63μm. depends on the diameter and number of the metal filaments incorporated.
Because the embroidery antenna is use electro-thread, and the electro tread is composed by conductive fibre, therefore the tread has resistance, is Ω per centimeter. The conductivity can be calculated by the equation:

$$K(conductivity) = \frac{1}{\rho} \tag{2.3}$$

Another unit is used to describe electro-threads, is called denier(D), for embroidery antenna can use 70D,100D and 200D. When the thread twists the resistance will increases as well, this is happened in 70D,100D and 200D. Because the impedance of the feeding probe is 50Ω, the higher resistance may have good performance in good impedance matching, then resulted in good reflection coefficient [9]. The embroidered circuit can not be directly soldered as polyester yarn melts under high tempreture.To be able to attach a connector to the texitle feeding line, thin copper film with conductive layer whould be sewed to the circuit. This technique allows good electrical as well as flexiable mechanical contact between textile transmission line and coaxial connector and feeding circuit.

There is other method technique could be sewing technique, there are two types of sewing method, one is fill stitch and spiral stitch.The difference between those two sewing method would be the spiral stitch method is alway sewing along the direction of meandered line; the fill stitch sewing method is not sewed along the direction of meandered line.
the figure 2.7 shows fill stitch. For the spiral stitch is in figure 2.8: For the measurement

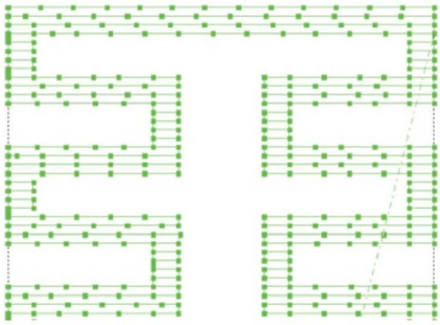

Figure 2.7: Fill Stitch

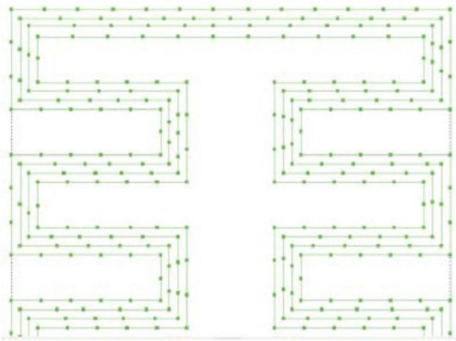

Figure 2.8: Spiral Stitch

of the recieved power in both embroidery method, and compare with the copper tape antenna(another technology for flexiable RFID tag), the copper tape performance better compared with embroidery antenna, and comparing with two differenct sewing method, spiral stitch method is better compare with fill stitch method.But for the S_{11}, reflection coefficient, the embroidery antenna is better compared to the copper tape [10] the reason can be explained by the loss for the conductive threads is higher than the copper material.

In the emboridery process, need to setting the the upper threads and lower threads, and also there are some parameter will affects the performance of the embroidery antenna. The first one would be stitching direction, there are three direction for stitching, stitched in vertical direction, horizontal direction and also the antenna can be stitched in diagonal direction. For obtained the good performance of the emboridery antenna, the stitched direction should be following the current flows, this method would be resulted in good performance of the antenna.

Another factor would be affected the embroidery antenna would be the density for the stitching. As metioned above, the current follows determined the the direction for the stitch, but if increasing the stitching density, the current would be not extact follows the direction the the stitching, and also the current may jump between two threads, therefore, the density is another important factor may affecting the performance of the antenna.

Chapter 3

Design and Prototyping of the Rectenna System

In this chapter, will discusses the requirement for this antenna, and design procedure in detail,be able to achieve this project. This section will go through the consideration, methods used in designing and how to improve the design to satisfy the requirement, thus achieved the overall project.

3.1 Microstrip Patch Antenna

To achieve this project, will starting at design a basic microstrip patch antenna, and simulated by using CST Microwave software.The antenna we designning should can be operated at 5GHz ISM band frequency.

3.1.1 Requirement

The microstrip patch antenna should satisfy those characteristics:

- The microstrip patch antenna should be operated at 5GHz ISM band frequency.
- The size of the antenna should be small or moderately size which can be applied in commercial and industrial application.
- The bandwidth of the antenna should be sufficient wide, can operate more frequencies.
- The antenna should has sufficient efficiency to collect RF signal from reasonable distance.

3.1.2 Methodology for Design

To design this microstrip patch antenna, the first step would be determined the suitable material for both patch and ground, and also for the substrate. The material selection will limited by stock of university. The material would be used for both patch and ground, is copper, for fabricate this microstrip patch antenna, the conductive yarn would be copper threads.Therefore, the material would be used for both patch and ground is copper. After detrmined the material used for both patch and ground, new material need to imported into the CAD(computer-aided-design) tool. Identify the permittivity, measuring the thichness of the substrate. The substrate selecting is depanding on the stock in university.The height of the substrate is between of 2-2.5 mm, this is obtained from measuring by hand, and the permittivity for this substrate is $1.2\epsilon_r$, therefore in the CAD(Computer-Aided-Design) tools, setting the new material which is for substrate, the height would be equal to 2mm at begining, and keep tuning the height for obtaining the good result, This substrate has low dielectric const and low thickness substrate material, this would be resulted in large dimension for the microstrip patch antenna designing, be able to enhanced the bandwidth.
After selecting the substrate used in this project, the next step would be determining the dimension for the patch. In literature review the length and width can be obtained by using equations

$$L \approx 0.49 \times \frac{\lambda}{\sqrt{\epsilon_r}} \tag{3.1}$$

and

$$W \approx \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \tag{3.2}$$

The calculation results for length was 21.35 mm, and the width was equal to 24.66mm by this calculation.The dimension for the ground plane are double the length and width of the patch respectively. In the microstrip patch antenna design, both width and length are important parameters, the length would effects the resonant frequency, in this case keep tuning the length that make sure the resonant frequency at 5GH.
The width is also important for microstrip patch antenna, the power radiation will increasing since the width of the microstrip patch antenna increasing, that would be result in improve the bandwidth, decreased resonant resistance and also increased the radiation efficiency, and also the width may slightly change the resonant frequency and radiation pattern.
Another thing is important is to determined the dimension for the feeding line which is located on them middle point for edge of the width.
Since the parameters for the substrate has been decided, and the dimension for the patch are calculated, can start using CAD(computer aided design) tool which is CST Microwave Studio to generated the 3-D model for the microstrip patch antenna. The calculation result is approximate result, the resonant frequency could be somewhere around 5GHz, and also the general rectangular microstrip patch antenna will gives a narrow bandwidth

antenna. Based on this preliminary design, can applied slot for the antenna, and using empirical

fine tuning to change the dimension of the antenna, dimension of the slot and also dimension of the feeding line.
The final design is shown below: The figure A.3 shows the final prototype for this mi-

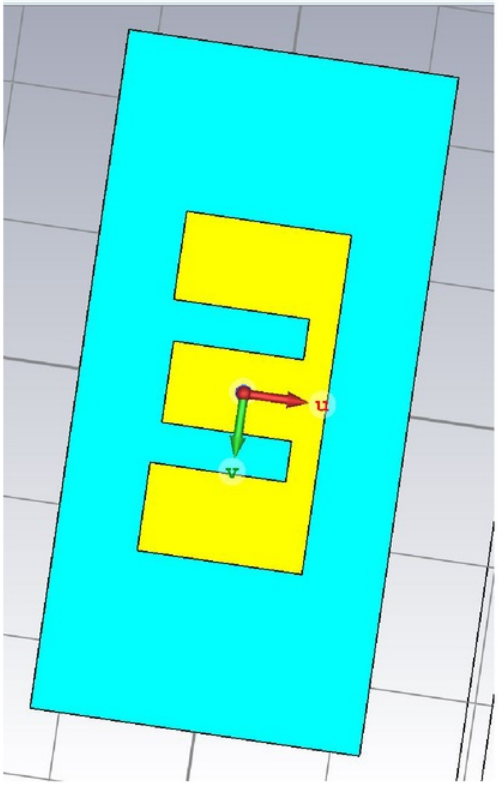

Figure 3.1: 3-D Model for Microstrip Patch Antenna Prototype

crostrip patch antenna, and it is the optimum design, and also the parameter for the final microstip patch antenna is shows in appendix.
The final width is equalt to 50mm, and the final length is equal to 24.3mm; the dimension of the slot is equal to 19mm(L)×24mm(W),the dimension for the feeding line is equal to 12mm(W)×19mm(L)

Chapter 4

Simulation Result and Discussion

This chapter will displays and discussed the simulation result obtained from simulation software. The simulation software used in this project, as metioned above is CST Microwave Studio. For simulate antenna part, time domain solver is set for calculate the development field through time at discrete location and at discrete time samples. The time domain solver is based on Finite Intergration Technique and it works on hexahedral grid(solver setting), therefore time domain solver is high efficiency for high frequency application, and also this solver can obtain the whole boardband frequency behaviour of the antenna. For the rectifier circuit, a transient task is going to analysing the behaviour of the circuit for an arbitary excitation in time domain.The external port is going to define the input, and the porbe located on the output is measure the output for the circuit. The rectenna is combine the antenna poart with rectifier circuit part. Similar as simulation of the rectifier circuit, the output would be how many RF signals obtained from antenna, then convert into DC signals. Another part in this chapter will discusses the result for simulation, the factors may affects the performance and how to improve the design.

4.1 Microstrip Patch Antenna

After the simple microstrip patch antenna has been create, the original configuration is rectangular microsrip patch antenna within a rectangular slot, the CST Microwave Studio can simulated the result. The key result for the antenna is S_{11} which is under 1-D result in navigation tree. The result for the original design is shown below, as figure 4.1

The S_{11} is used to measure the return loss, From the graph can see the resonant frequency at 4.977GHz and the antenna is narrow band.At the $S_{1,1}$ lower than -10dB,the bandwidth is equal to 0.23977 GHz which is 239.77 MHz. The bandwidth of this antenna still can improve, and also the resonant frequenc need to switch to 5 GHz by changing the length of the antenna.

For the purpose to imporve the narrow band, the antenna can be improved by increasing the height of the substrate and slot for the antenna.After the improvement simulated

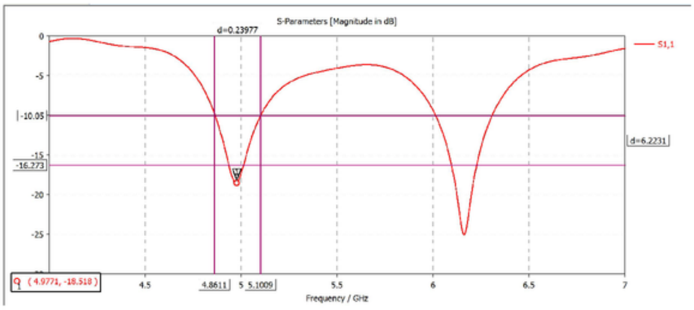

Figure 4.1: Return Loss for Original Design

the antenna again. The result shows in figure 4.2:
The bandwith for this antenna has been improved to 0.3479 GHz which is 347.9 MHz,

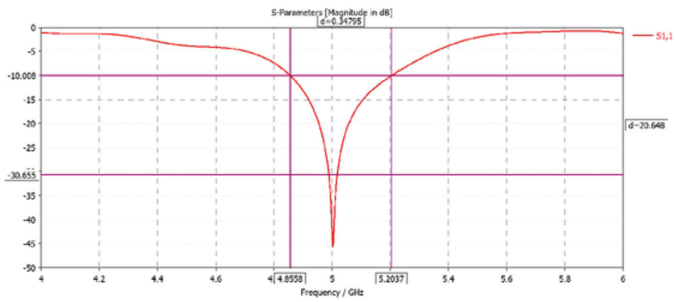

Figure 4.2: Return Loss for Improvement Design

and the resonant frequency is equal to 5GHz. To obtained the acceptable result from the simulation, there are many parameters are keep keeping tunning. For the purpose of increasing the bandwidth, there are two things are keep tunning, one is the height of the substrate, another is the slot applied in the microstrip patch antenna.
In this microstrip patch antenna designing, the substrate is used has low dielectric constant, be able to get wide bandwidth, would be resulted in larger dimension for the antenna.
For the commercial and realistic purpose the microstrip patch antenna is going to stitched on fabric or cloths, can not be very large, Therefore the bandwidth for the microstrip patch antenna, can improve the electical dimension rather than physical dimension.As metioned in literature review, the fridging effect can increasing the electical dimension compared to the physical dimension.
In the simulation result, the bandwidth can be improved as the height of the substrate increasing, but the height of the substrate is limitated by the pysical properties of the substrate material is used in embroidery antenna, the maximum height of the substrate material is 2.5mm, since the height of the microstrip patch antenna has reached to the

maximum height. This design can start to tunning the dimension of the slot.
In this type of design the dimension of the slot is increasing, this would be resulted in improved the bandwidth, and also this method is based on the fridging effect, increasing the electrical dimension compared to the increasing the physical dimension.Before the dimension of the slots reached to the maximum dimension, since the dimension increasing ,the bandwidth is increasing as well.
In the appendix, the parameter for the final microstrip patch antenna are shown in the table. Another important or purpose of the antenna is going to investigate the efficiency of the antenna, It is can be obtained from farfiedl simulation navigation tree. The following two figures shows the directivity of the antenna, and the realized garin for this type of the antenna.

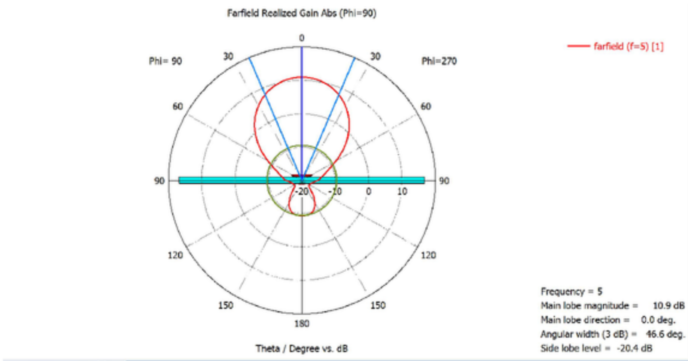

Figure 4.3

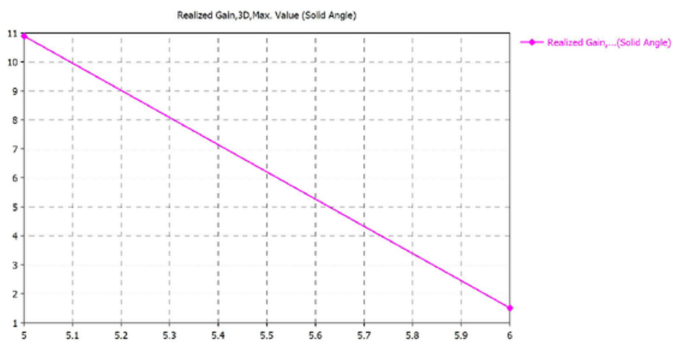

Figure 4.4: Realized Gain

From those two figures, can see the realized gain at 5GHz is 11dB, has been obtained which is relatively good considering the size of the antenna array and the feed technique used. This gain is a signiffcant improvement over the single patch microstrip antenna and hence it can be said that this antenna array has successfully achieved its requirements relating to an increase in gain. From an estimation calculated using the Friis equation. This gain is a signifficant improvement over the single patch microstrip antenna. Another thing is used to calculated the efficiency is main lode magnitude, this parameter can be obtained from figure 4.4 The calculation is following:

$$efficiency = \frac{10.9}{11} \times 100 \tag{4.1}$$

After the calculation the efficiency is equal to 99%

Chapter 5

Manufacture Embroidery Antenna

In this chapter will discusses the embroidery antenna processes. The machine used, and the key consideration for embroidery antenna. The CAD tool used in this project, computer control embroidery machine.This chpater will discusses how to digitizing the image and setting the machine, and also will discusses the key consideration will effect the antenna's performance.

5.1 Design the Emboridery Antenna

The first step should do is digitizing the patch and ground, in this procedure, the digitizing software PE Design 10, would be used to set the shape of enbroidery antenna, the density of the antenna, and pull compensation for this antenna. From the literature review, in order to get good performance for the antenna, the sewing direction should follow the curent flows [7]. According to the current flow at simulation result of the antenna resonant frequency at 5GHz, the current is follows in horizontal direction.This result is shown in figure 5.1 Therefore, for obtains good antenna's performance, the sewing direction should be in horizontal, by setting the stitch direction 0^o manually. From the simulation result the current is not always follows in horizontal direction, in some parts the current follows in vertical direction. For solving this problem, can increasing the sewing density. Since the density is enough high, the current would not just follows the line, also can jump between two lines. That is one way to imporve the embroidery antenna, to increase the density of the antenna, in the PE Design 10, should setting the density equal to 3.0/mm. This is optimize choice for the antenna, the high density may cause stretching the fabric, reduce the size of the antenna, for solving that, PE Design 10 can added pull compensation for the antenna, to maintain the accurate size.
After digitizing and preset the antenna is going to emboridered, can input the files into the emboridery machine. Adjust the position is going to emboidery, set the upper threads and lower threads. The upper threads is cotton threads and lower threads would be copper threads, the reason for doing that, if using copper threads as upper threads, the copper threads path is long and more frictions occurs, the frictions may break the threads easily. For lower threads no friction occurs, reduce the risk to break the copper threads. The

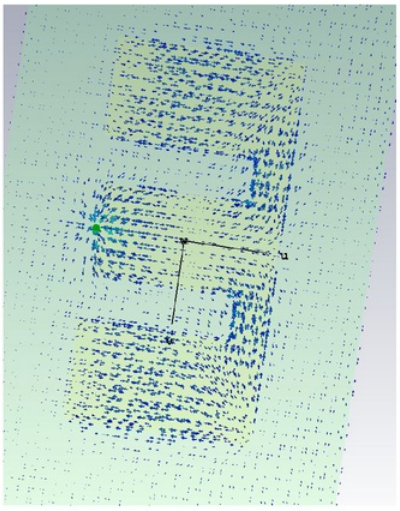

Figure 5.1: Current Flow at 5GHz

emboridery machine can set the tension for upper threads and lower threads manually, the tension for both upper and lower threads should be balanced, otherwise distortion may occurs, then affects the dimension for the final antenna. The tension for the upper threads is 5.2, and it should be balanced to the lower threads tension which is can be setting manully.

After setting the emboridery machine, can starts to emboridery.Both patch and ground should be emboridery on the polyester fabric, and adhesive patch and ground together with the substrate fabric in between.

Initially, because fo the high density of the stitching and the tension for the threads, the contraction occurs for the width.After measuring the width for the embroidery antenna, compare to the design, then set pull compensation equal to 1.2mm, then measured the size for added pull compensation, the dimension should be really close to the design. After patch finished, same setting parameter and procedure for stitched the ground.
After finished stitched both patch and ground, should be adhensive thoses two together within substrate in between, the substrate is given by Macquarie University stock, and also need to added feeding probe, the feeding method used in this antenna is probe feeding, which insert the probe vertically from patch to ground through substrate. The final antenna is shown in figure 5.3

Figure 5.2: Embroidery Setting for patch

Figure 5.3: Embroidery Setting for Ground

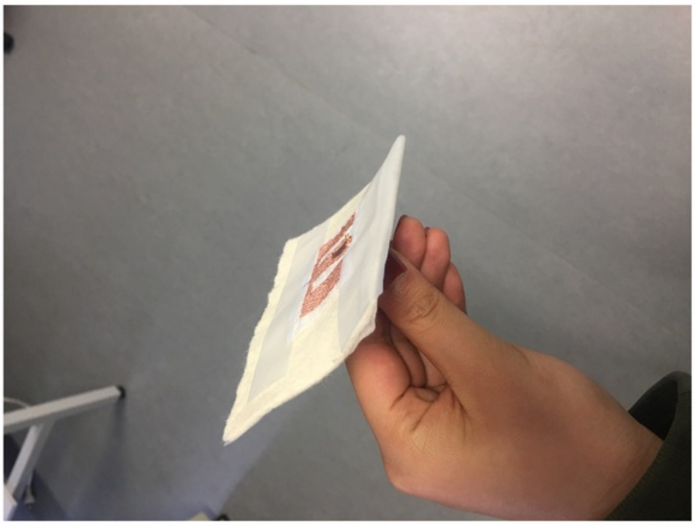

Figure 5.4: Embroidery Antenna.

Chapter 6

Physical Testing

This chapter will go through the physical testing for the antenna, compare the performance with the simulation result. and discusses the performance of the antenna. The physical testing was undertaken at Macquarie University Research Laboratory.The equipment and method will go through in this chapter.

6.1 Emboridery Antenna

In this section will test the Reflection Coefficient Parameter Matching, Resonant Frequency, and check with simulation result.
First, need to set up the experiement, in the physical testing the equipment will used is called Agilent Technologies N5242A PNA-X Network Analyser, this network analyser is sensitive to any static discharge, therefore need to caution all the time when using this network analyser, wearing the anti-static wristband is required. Before measuring the antenna by using this equipment need to calibrated by using Agilent N4691-60006 electronic calibration module that make sure the results obtained are highly accured.

After calibrated, can start to testing the antenna. Connected the emboridery antenna to the channal one of the network analyser by coneecting the feeding probe of the embroidery antenna to the coax cable, and place the antenna in the free space. Take three measurement, antenna is the free space, interface at back and interface infront of the antenna, take the data, and draw the graph for the data.

6.2 Result for the Physical Testing

This section will displays the results mesuared from the network analyser.In the physical testing there are three conditions are tested, interface at back of the antenna, the result is shown below:

Another condition is going to tests, is when the interface is happen infront of the antenna, the figure 6.4 shows the performance for this condition.

Figure 6.1: Calibration

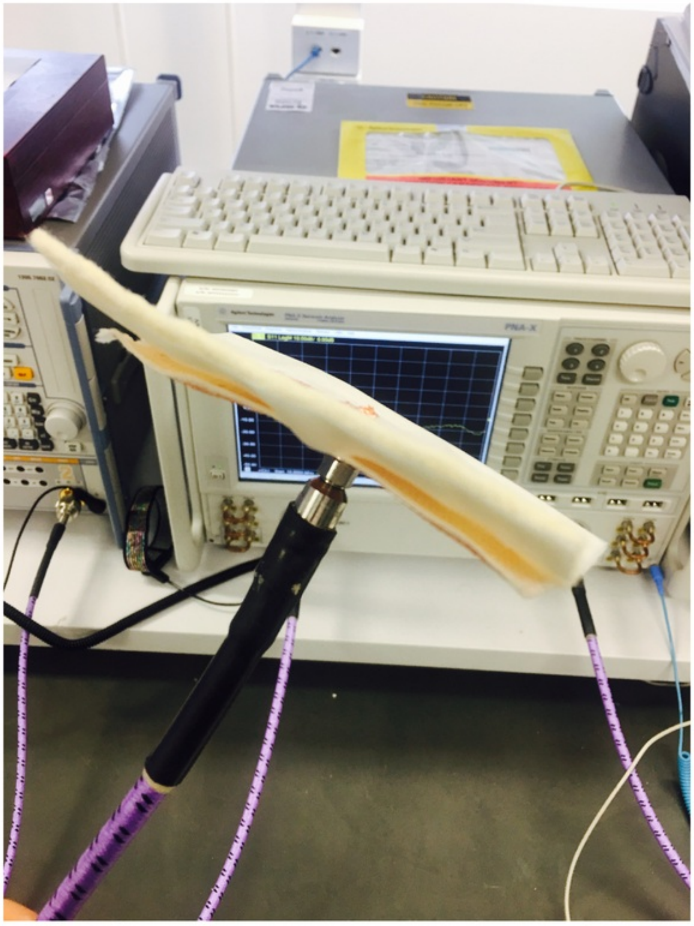

Figure 6.2: Physical Testing for Embroidery Antenna

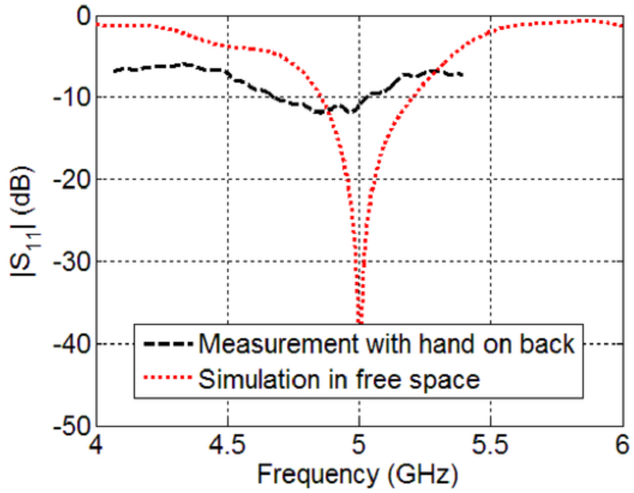

Figure 6.3: measurement of hand on back

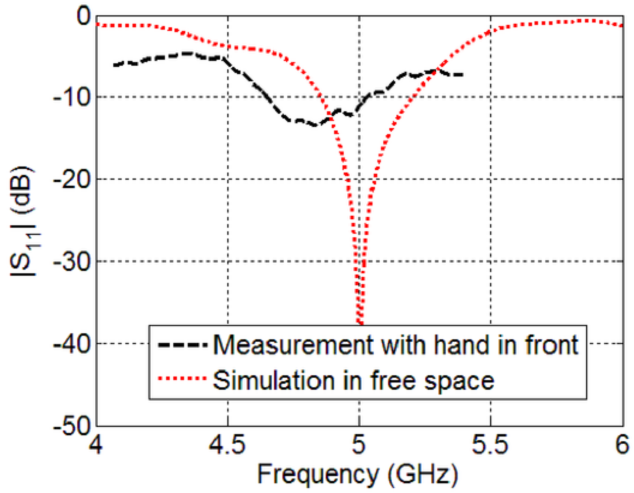

Figure 6.4: Hand in the Front

The last condition, is tests the performance of the antenna is free space, which is means no any interface happened infront and at the back. The results is given in figure 6.5

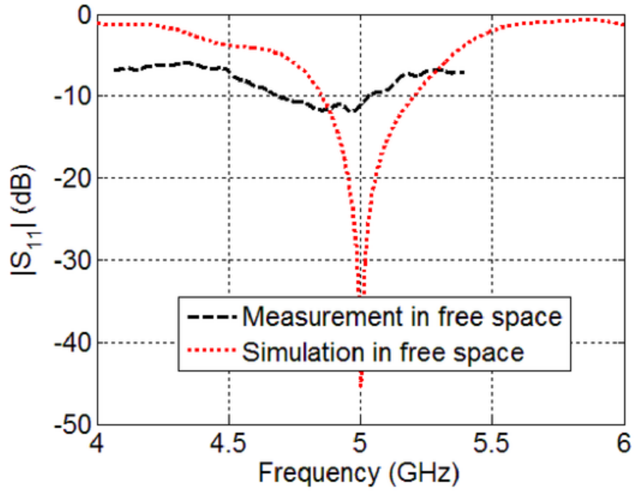

Figure 6.5: Measurement in Free Space

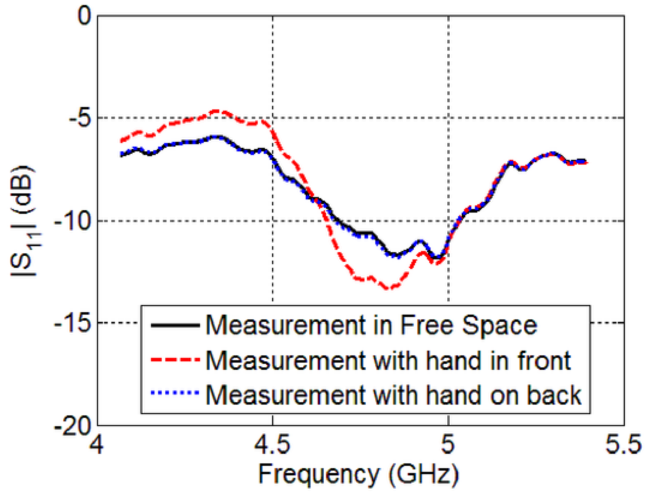

Figure 6.6: Measurement Comparison

6.3 Discussion

From the results, shows the bandwidth is sufficient large, the bandwidth has been improved, but there still have somethinds lost, the resonant frequency has shifted to the left, and the impedance matching is not perfect as simulation. The reason why the resonant frequency has beed shifted, because the antenna is stitched on, according to the equation below

$$\lambda = \frac{c}{f} \tag{6.1}$$

The c is speed of light, and it is constant,usually equals to 3.00x$10^8 m/s$, λ is wavelength, and f is resonant frequency, From the above equation shows, the resonant frequency is inversly propotional to wavelenth, since the lenghth is increased,therefore the resonant frequency will decrease, which is shifted to the left.

The phyical testing result is not as perfect as simulation result, even the bandwidth for the embroidery antenna is acceptable, but the reflection coefficient does not as lower as simulation result, which is not good performance in impedance matching, and also the it is unstable compared to simulation result.

The reason for not performance a good impedance matching, cause the emboridery is not perfect, this will resulted in the dimension for the embroidery antennna is not perfect as prototype produced by simulation software,and also the surface is rough, and due the embroidery process, threads broken occurs somewhere and re-starts again, will gives the density for the stitching in uneven those factors may affect the performance of the antenna, but still resulted in good bandwidth.

The performance for obtained the emboridery antenna, from the results can see, when measuring in the free space and interfaced in the back of the antenna, there are slight different for those two results.That is shows any interfaces in the bak of the antenna, does not affects the antenna too much, which is really good for antenna, becaused the ground would be attached to human body, not affect from back of the antenna would not affects performance of the antenna, and would not cause any danger for human body. The affects only affects when the interface is infront of the antenna. Thats shows the antenna does work for obtains RF signals from ambient emvironment.Also the results obtains from physical testing compared to the simulation results shows that the bandwith is still sufficient large. The bandwidth has improved but the lost some reflection coefficient, does not perform good impedance matching Because of the antenna is obtained the RF signals from ambient environment, the antenna is really sensitive, the performance would be affectd by any slightly change, in position, the way to interface and so on.

Chapter 7

Conclusions and Future Work

This chapter will go through the conclusion and state the furture work related to this project,

This project has successfully created a good performance antenna, good bandwidth, good efficiency and resonant frequency is at 5GHz. This report has discussed the basic theory support this porject designing,for the microstrip patch antenna and embroidery antenna theory, the affectors would affecting the performance and the designing considieration. The CAD(computer aided tool) used in this simulation which is called CST Microwave Studio, discusses the prototype of the microstrip patch antenna in details, the materials used and parameters for those materials. After finished prototype of the microstrip patch antenna, can simulated the result, make sure the resonant frequency of the microstrip patch antenna is 5GHz, and the bandwidth has been improved.
After simulation, should be fabricated the embroidery antenna by using PE Design 10 to digitizing the dimension of the patch and grounds, and use computer embroidery machine to embroidery the antenna, then can start to physical testing the antenna.Compared the tested result with the simulation results, the bandwidth is still sufficient large, but lost some impedance matching for the performace of the embroidery antenna.Discussed the factors may affect the performance of the embroidery antenna.
In the last section will state the future work in short term future work and long term future work related to this project.

7.1 Future Work

This section will discussed both short term future work and long term future work related to this project. The short term Work will included:

- Applied or connected the rectifier circuit to investigate the performance of the overall rectanna system.
- Applied the voltage multiplier for the rectifier circuit to increase the output voltage, in order to improve the

- Improve the embroidery setting and improve the embroidery method to reduce the lose may occurs during in fabricated. In order to improve the impedance matching of the embroidery antenna.

The long term future work will affects and can be achieved in the long terms.

- Improve the shape for artistic purpose, and remains the good performance of the antenna, such as good bandwidth and good efficiency.
- Investigate the material used to embroidery antenna, the properties for the material has good conductivity and good strength.
- Improve the overall design make is more lighter, more flexble, and easy to wear, the surface is more smooth, when wearing the embroidery antenna, more comfortable.
- Improve the design more compacts size, and used in commercial purpose.

Chapter 8

Abbreviations

MPA	Microstrip Patch Antenna
MIC	microwave integrated circuits
AC	Alternating Current
BW	BandWidth
ISM	Industrial-Scientific-Medical
dB	Decibels
DC	Direct Current
RF	Radio Frequency
CAD	Computer Aided Design

Appendix A

name of appendix A

A.1 Overview

This part will shows some Preliminary design for this project before decided the final or optimize design for this project. First one is basically rectangular microstrip patch antenna, and following design is the improvement design which are based on the basically rectangular microstrip patch antenna, and also the table shows the parameter used for the final disgn.

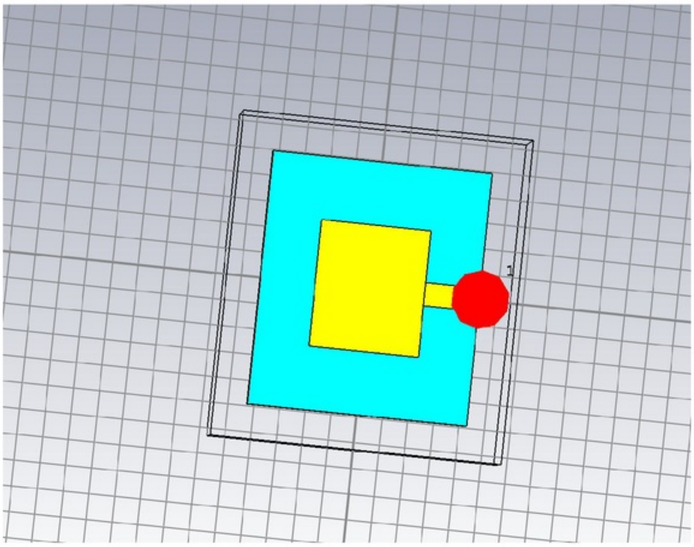

Figure A.1: Preliminary Design

A.2 Consultation Mettings Attendance Form

Consultation Meetings Attendance Form

Week	Date	Comments (if applicable)	Student's Signature	Supervisor's Signature
	17/08/02		李辰星.	RM.
	17/08/08		李辰星.	RM.
	17/08/16		李辰星.	RM.
	17/08/~~23~~		李辰星.	RM.
	17/09/03		李辰星.	RM.
	17/09/07		李辰星.	RM.
	17/09/25		李辰星.	RM.
	17/10/05		李辰星.	RM.
	17/10/~~12~~.		李辰星.	RM.
	17/10/20		李辰星.	RM.
	17/10/27		李辰星.	RM.
	17/11/02.		李辰星.	RM.

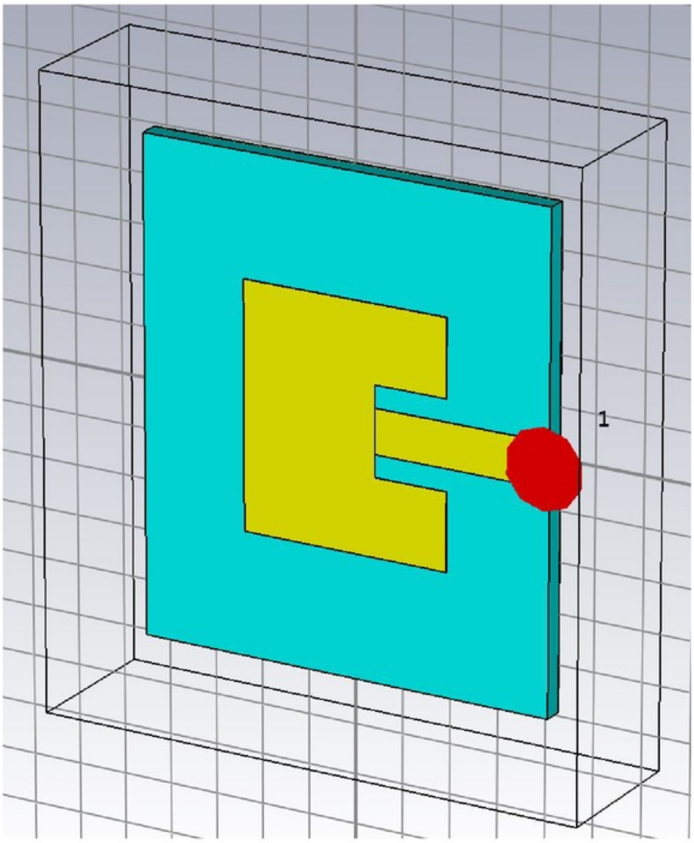

Figure A.2: Improvement Design

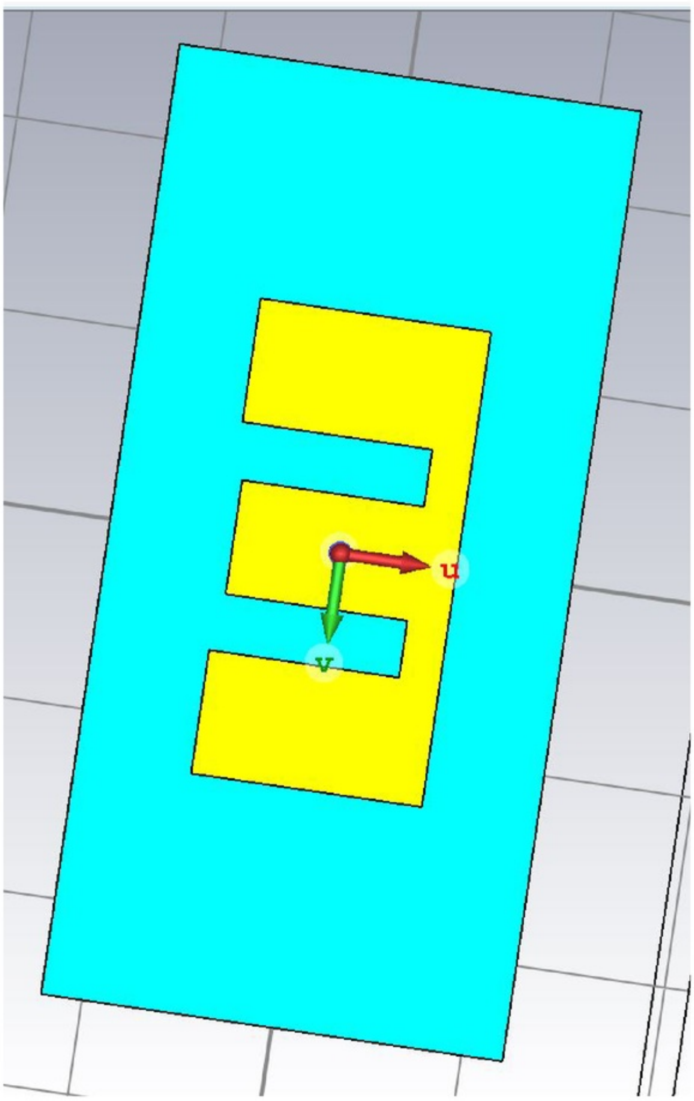

Figure A.3: Final Design

Name	Expression	Value	Description	Type
g length	= 2*p length	48.6		Undefined
g width	= 2*p width	100		Undefined
sub t	= 2.5	2.5		Undefined
p length	= 24.3	24.3		Undefined
p width	= 50	50		Undefined
p loc	= -10.675	-10.675		Undefined
insert space	= 20	20		Undefined
T line	= 12	12		Undefined
Inset length	= 7	7		Undefined
empty space	= 8	8		Undefined
distance	= 100	100		Undefined
insert length	= 7	7		Undefined
<new parameter>				

Figure A.4: Parameter for final Design

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