DESIGN OF RADIO FREQUENCY IDENTIFICATION (RFID) TAGS FOR DISTRIBUTION TRANSFORMER REAL TIME DATA TRACKING SYSTEM

MUHAMMAD HIDAYAT BIN MOHTAR APANDI

A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering (Electronics System)

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2019

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature	:	
Name	:	MUHAMMAD HIDAYAT BIN MOHTAR APANDI
ID No.	:	18UEM00847
Date	:	12th MAY 2019

APPROVAL FOR SUBMISSION

I certify that this project report entitled **“DESIGN OF RADIO FREQUENCY IDENTIFICATION (RFID) TAGS FOR DISTRIBUTION TRANSFORMER REAL TIME DATA TRACKING SYSTEM”** was prepared by **MUHAMMAD HIDAYAT BIN MOHTAR APANDI** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering (Electronics System) at Universiti Tunku Abdul Rahman.

Approved by,

Signature	:	
Supervisor	:	Ts. Dr. Lim Eng Hock
Date	:	

Signature	:	
Co-Supervisor	:	
Date	:	

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, **Ts. Dr. Lim Eng Hock** for his invaluable advice, guidance and his enormous patience throughout the development of the research, for suggesting the research point, his valuable guidance and help, continuous encouragement, which have made this research possible and for the valuable discussions throughout the stages of this work.

In addition, I would also like to express my gratitude to my loving parents and last but not least to my beloved wife **'Aisyah Binti Daud** for her continuous support and encouragement.

Finally, thanks for everyone who has helped me with this thesis.

Muhammad Hidayat, 2019

ABSTRACT

This thesis present a compact sized passive radio frequency identification (RFID) tag embedded in thin metal cavity carved out of small metallic parts operating at ultrahigh frequency band for identification and tracking of distribution transformer manufacturing status. The proposed tag consists of two rectangular quarter-mode patch antennas printed on $23 \times 23 \times 1$ mm^3 copper-clad-alumina substrate ($\mathrm{Al_2O_3}$) arranged properly to robust the tag's performance when the tag embedded in small metal cavities carved out of metal objects.

To protect the tag during operations from impact or damages, the application of commercial epoxy resin is considered during the design process to reduce the tag physical size. The tag performance simulated in computer software 3D simulation CST Studio Microwave, numerically analysed and discussed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

RFID	Radio Frequency Identification
UHF	Ultra High Frequency
HF	High Frequency
LF	Low Frequency
EIRP	Equivalent Isotropic Radiated Power
MTM	Malaysia Transformer Manufacturing
TNB	Tenaga Nasional Berhad
WIP	Work In Progress
PIFA	Planar Inverted-F Antennas
EM	Electromagnetic
ETSI	European Telecommunications Standard Institute
IC	Integrated Circuit
cm	centimetre
m	meter
Hz	Hertz
MHz	Megahertz
kHz	kilohertz
GHz	Gigahertz
dB	decibel
dBi	decibel isotropic
dBm	decibel meter
mm	millimetre
U	radiation intensity
W	watt
P_r	power transmitted by the reader
G_r	reader gain antenna
G_a	gain of tag
λ	wavelength,
r	the distance between the tag and reader.
Z_a	antenna impedance
Z_c	chip impedance
Ω	resistance

D	Directivity
P_{th}	threshold power
RF	radio frequency
ε_r	relative dielectric permittivity
tanδ	loss tangent
τ	power transmission coefficient
R_a	antenna / tag resistance
X_a	antenna / tag reactance
R_c	chip resistance
X_c	chip reactance

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Radio Frequency Identification (RFID) technology has gained popularity as one of the important element in the current trend of Fourth Industrial Revolution (IR 4.0) and Smart Factory concept as automatic identification to track and managing material or products in the manufacturing line (Lechner *et al.*, 2016). The technology consists of an antenna attached to the desired objects with stored monitoring information and readers that read the stored information from the tags. The energy emitted by the reader used to transmit data from the reader to the tag and back to the reader.

RFID systems can be distinguish in two categories which are active and passive. A passive RFID operates when the reader transmits modulated radio frequency (RF) signal and the energy supplied to the tags through electromagnetic field from the reader will be used to respond by varying the input impedance of the integrated chip, thus the field of the reader can be modulated either by load modulation or modulated backscatter. If the tag is located outside of the reader's range, the tag has no power supply and therefore the tag will not be able to respond. On the other side, by using active RFID, the electromagnetic field received from the reader are not necessary to supply power to the chip because the chip will use the energy supplied from a battery or a solar cell. The advantage of active RFID is the reader's field may be much weaker than the field required to operate a passive tag and significantly increase the read range if the tag are capable to detect a weaker reader signal. The constraint encountered when using active design is an active tag are just able to modulate the reader's field in order to transmit the data back to the reader and not contributed to the performance of data transmission. Hence, the RFID system may vary from one to another depends on its designed functional specifications, detection feature and field of applications (Finkenzeller, 2003).

The frequency range of RFID systems can be classified into four frequency range which is low frequency (LF, 125 kHz – 134 kHz), high frequency (HF, 13.56 MHz), ultra-high frequency (UHF, 860 MHz – 960 MHz), and microwave (2.4 GHz,

- 5.8 GHz) (K.~S.~Rao, P.~V.~Nikitin and S.~F.~Lam, 2015). The electromagnetic spectrum as shown in Figure 1.1 are the ranges of operating frequency of RFID tags.

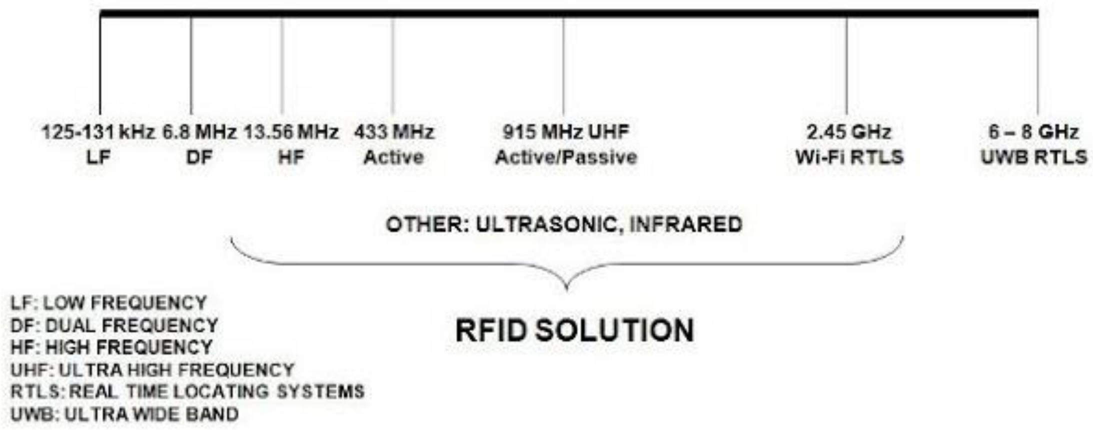

Figure 1.1: Electromagnetics spectrum of RFID antennas.

It is imperative to select the right operating frequency for RFID because electromagnetic waves behave differently at different frequency. As an example, LF systems are ideal to track reading objects with high-water content, such as fruit or beverages with liquid contents, but the read range is limited to centimeters or inches. Typically LF RFID applications are used for access control and animal tagging.

HF frequency tag work in ranges of inches, but they can have a maximum read range of about three feet (1 meter) and work best on objects made up of metals and goods with high water contents. Basically, HF RFID applied in transit ticketing system and tracking library books.

UHF RFID offers a much better option for long range identification and monitoring data can be transferred faster in UHF medium rather than LF and HF. But due to its short wavelength, the signals are easier attenuated or weaken and cannot pass through thin metal or water. UHF system are used commonly in parking access control and toll fare collection.

Therefore, in this research passive UHF RFID systems are preferable compared to HF and LF RFID systems because long read range ability gives advantage to detect the desired components without approaching or touching the components. However, UHF RFID possesses two disadvantages: a) large antenna size, b) high sensitivity to the metal objects on which the tags is placed. Those two deficiency are causing a large number of small sized objects and metal objects hard to tag.

In this paper, a UHF RFID tag design was proposed and chosen to be used for remotely tracking the movement and location of manufactured distribution transformer in manufacturing line at Malaysia Transformer Manufacturing Sdn. Bhd. (MTM) - A subsidiary of Tenaga Nasional Berhad (TNB). By implementing RFID technology in production management level, it can bring a significant contribution to saving costs by helping to monitor work-in-progress (WIP) and improving process flow. WIP of transformer's manufacturing details that need to be kept at a particular stages at a specific planned manufacturing time or that is held as intermediate stock prior to final assembly can be tracked and identified. The view of manufactured distributions transformers located in the factory shown in the Figure 1.1.1.

Figure 1.1.1: Manufactured distribution transformer ready for delivery to TNB's storage in Peninsular Malaysia .

Most of transformer's tank was designed and built from mild steel. Therefore, it is very important to wisely choose a good RFID tag design and understand the behaviour of the electromagnetic field of the tag near metallic surface since the tag's parameters (the input impedance, gain , radiation pattern , and radiation efficiency) can be seriously affected by the metal surfaces. Near metallic surfaces, the electric field will be dispersed because metal surfaces reflect energy emitted from RFID readers and create interference which resulted to the failure on the tag to receive and transmit information.

The most common design used in the market for RFID tag are dipole antennas design due to cheap fabrication cost and easy manufacturing process. However, using dipole antenna for identifying metallic objects is not possible because the boundary conditions contributes to the deterioration factor of the RFID tag's performance, which makes the EM wave reflect from the metal surface with a condition where a phase reversed reflection wave cancels the incident wave and reduces the energy the tag antenna obtains to make the chip active. (Mo, Ling-fei & Zhang, Hong-jian & Zhou, Hong-liang. 2009).

Hence, the aim of this paper is to simulate a design of RFID tag which can work for remote identification and tracking of manufactured distribution transformer represented by a metal layer in the CST simulation software. Therefore, by using RFID system the efficiency and productivity of the workers at Malaysia Transformer Manufacturing (MTM) will be increases and asset tracking in the factory could be tracked automatically without relying on human intervention to manually track the transformer's location and statuses at a particular of time.

1.2 Importance of the Study

The research on performance improvement of RFID tag design, particularly to increase the read range and its accuracy, is always a challenge in electronics and manufacturing industry. The performance of RFID tag greatly depends on tag design, metal composition on which the tags will be located, impedance matching, interference from other RF devices and etc. In the past few years, there has been a surge and massive usage of RFID technology. Additionally, RFID technology still has not been able to replace the current bar code system in many companies due to its high cost of printing and producing RFID tag antennas (Zheng and Zhang, 2012). Therefore, this study is important as it addresses the following aspects:

a. The performance of designed UHF RFID tag consist of two miniaturized quarter-mode patches embeddable in small metal cavity is investigated and simulated using CST Microwave Studio.
b. To study the effect of commercial epoxy resin thickness on the tag readability by the reader.

1.3 Problem Statement

Based on the literature reviewed regarding

a. The development and design of compact RFID antenna / tag which suitable to be placed on metallic surfaces with low fabrication cost still remains a key research area.
b. Very little research has been introduced regarding the study of RFID performance in hostile operating environment to defaults normal use of RFID such as high electromagnetic interferences area, variance of temperature, humidity and harsh environment.
c. To eliminate the dependency on human vision and document control to monitor, record and track the distribution transformer manufacturing data by using RFID system in real time data monitoring.
d. Reduce human labour cost and increase working productivity of the production's operators.
e. Boost manufacturing line effectiveness to monitor manufacturing status and achieve customer's delivery targets.

1.4 Aims and Objectives

In order to study the performance of a UHF RFID tag before choosing it to be fully used in tracking metal components, this study embarks on the following objectives:

a. The performance of designed UHF RFID tag consist of two miniaturized quarter-mode patch embeddable in small metal cavity is investigated and simulated using CST Microwave Studio.
b. To study the effect of commercial epoxy resin thickness on the tag readability by the reader.

1.5 Scope and Limitation of the Study

The following limitations must be considered when interpreting the results of this study:

a. The design and modelling of the proposed UHF RFID tag used in this study was randomly selected and repeated in computer aided design software CST Studio Microwave to proven the previous results gained in.
b. This research did not included with the real field test to track distribution transformer manufacturing process, therefore the interference occurred in the

factory and during commissioning effecting readability of the tag is not considered.

1.6 Contribution of the Study

The main contribution of the study is to solve the problem of manual monitoring and tracking manufacturing data of distribution transformer in MTM. Therefore, a solution to track manufacturing data by using barcode was still practiced in many manufacturing company. But according to the current technology available and Industrial Revolution 4.0 concept, the future manufacturing are looking for remote monitoring options and to reduce the dependency on human intervention. The benefits from implementing technologies in manufacturing are undeniable can enhance the worker's performance, reduce human errors and contribute to gain a higher revenue of a company. Therefore, the research about RFID technology in this paper can be implemented to realise the desired objectives and get to brings a better working environment for every staffs and operators.

1.7 Outline of the Report

This thesis comprehend five chapters, which are arranged to present the background of study, literature review, experimental work, result, analysis, discussion and conclusions.

The chapter details are summarized below:

Chapter 1 contains the general view of the study background and offers the scenario of the problems to be investigated as the motivation of this study.

Chapter 2 presents the literature review of all matters related to the efforts to increase the performance of the RFID tag operating in UHF band. The relevant and similar concept from previous researchers are highlighted to help understand the main subject matter in this paper

Chapter 3 describes the experimental work and workflow of the research interest. The overview of how the research conducted, RFID design model, analysis and measuring parameters are stated.

Chapter 4 presents the analysis and discussion of the tag based on the results obtained from the simulation. An investigation was carried out to define the performance of designed RFID tag embedded in metal cavity covered in commercial epoxy resin. The parameters of the UHF RFID tag are measured and tabulated in this chapter to show the capability of the tag.

Chapter 5 concludes the findings and discussion of the study. Recommendations for further considerations and future research based on the findings in this project are suggested and proposed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A review of past research focus on the improvement of UHF RFID tag has gained interests in three basic areas:

a) Increase the reading capability of RFID tag placed on metal problems.
b) Collisions and overlap respond of RFID tag.
c) Mismatching of input impedance.

2.2 Increase the reading capability of RFID tag placed on metal problems.

Most tag antenna design available in markets are based on dipole antenna, therefore the performance on the tag could be degraded due to metallic boundary conditions which could be interpreted from the electric field mechanism illustrated in Figure 2.2.

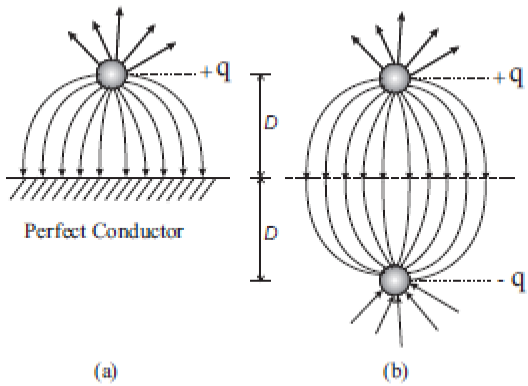

Figure 2.2: Electric field of positive charges put above on a conductor. a) single positive charge. b) positive charge and its images. (Hu, 2010)

Based on the Figure 2.2 above, when a single positive charge put above of a perfect conductor at distance D, the tangential electric field cannot pass through the perfect conductor and cancelled out because the electric field is absorbed by the conducting layer of the conductor itself. This metallic boundary condition concept proves the Maxwell’s equation: $\hat{n} \times E_2 = 0$, ($E_1 = 0$), where $\hat{n}$ is the vector which is perpendicular to the interface formed by two media and directed from medium 1 to medium 2, E_1 and E_2 are the electric field in medium 1 and medium 2 respectively. In order to obtain same electric field distribution, a negative charge should be placed underneath of the positive charge at an equal distance D.

As a conclusion, if there is any tag or antenna designed based on dipole antenna design, placed closely on the metal surface of a perfect conductor, the placed tag will not radiated because of the antenna's current cancelation between the tag and its image.

2.3 Collisions and overlap respond of RFID tag.

In one research by Kim et al. in 2009, problems related to find a solution to control readability of multiple tag in one time. The tag collision in this case is described as the collision resulting from a multiple response of tags within the electric field range of the reader. A complex tag collision algorithm where 5 steps of control method were introduced.

The method of configuring a fixed number of readers into groups, classifying readers into master reader and slave readers and using frequency hopping technique to prevent collision with other groups was discussed (Kim et al. 2009) according to the Figure 2.3 below.

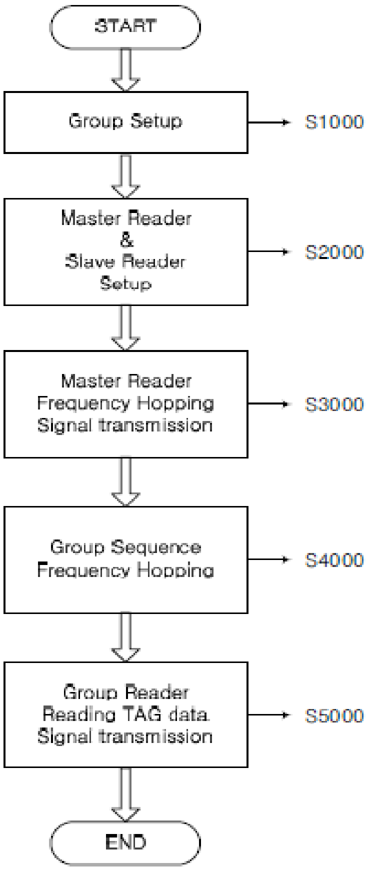

Figure 2.3 : Flowchart of Multiple RFID control method. (Kim et al. 2009)

In a brief, the proposed control method for multiple RFID tags that can minimize collisions and interferences to the readers of UHF RFID system could be useful in a condition where multiple tags and readers are used to track and identify multiples item at one time.

2.4 Mismatching of input impedance

Impedance matching in electronics industry is practiced to design the input impedance of an electrical load or the output impedance of its corresponding signal source to maximize the power transfer or minimize the signal reflection from the load. The simplified equivalent circuit of RFID tag is shown in Figure 2.3 below.

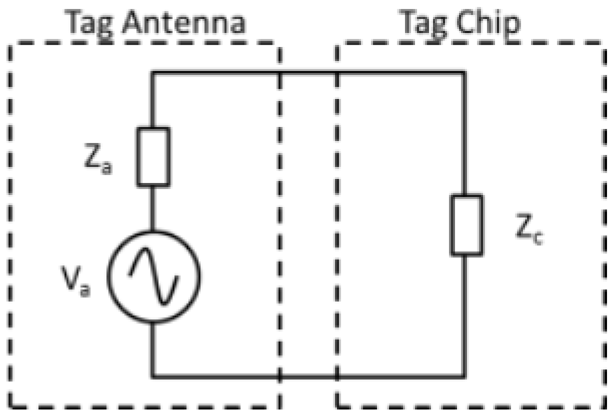

Figure 2.3: Equivalent circuit of RFID tag and chip. Where V_a, voltage supply, $Z_{a,}$ antenna impedance, $Z_{c,}$ chip impedance.

The variation of input impedance issue in RFID field has been discussed deeply and proven by previous experimental research (Nikitin and Rao, 2006) (Prothro, Durgin and Griffin, 2006). The impedance of the tag mismatch impedes the maximum power transfer from the antenna to the load. The reading range and input impedance of several commercial tags were measured at varies distance on metal plate. The result obtained showed that all of the tag sample could be read in near proximity less than 2 mm on metal plate (Konishi, T. *et al.* 2009) .

In an experiment conducted by Prothro et al., supported that variation of the input impedance in RFID caused by geometrical dimensions and leads to the power transfer efficiency to the load degraded when a RFID tag put closed to the metal surface objects. In their work, either by using a narrow silver paste strip or a broad of silver paste strip was used to fabricate two folded dipole antenna. It was found that both of the real and imaginary parts of the input impedance of the narrow strip are less sensitive to the foreign metal object than those of broad strip antenna (Prothro, Durgin and Griffin, 2006).

In another research by Konishi et al, the experiment conducted on a UHF RFID tag to match the input impedance by using parasitic element was introduced. Regardless of the facts that the input impedance of the inlet antenna is affected by a vicinal high impedance surface (HIS) , parasite elements on the HIS can successfully recover the original input impedance and lead to a good matching to the IC chip without any modification to the tag antenna itself. A better input impedance was achieved by placing two parasitic elements parallel to the tag antenna made up of copper put on a polyethylene foam spacer with the thickness of 1.1 mm in a condition where the input impedance of the tag is controlled by changing the coupling effect between the tag antenna and each of the parasitic elements . The input impedance was controlled by changing the length of the parasite element and distance from the tag antenna (Konishi *et al.*, 2009).

2.5 Summary

The following conclusion is reached after a comprehensive review of previous published research works in electronics field. A few studies introduced refer to discover the disadvantages performance of dipole antenna design when placed on metal surfaces. There are many parameters and variables that need to take into account during the design process of a tag to achieve the desired result.

Hence, the aim of this work is to obtain the simulation result to study the performance of designed UHF RFID tag consist of two miniaturized quarter-mode patch embeddable in small metal cavity simulated using CST Microwave Studio. Secondly, to study the effect of commercial epoxy resin thickness on the tag readability by the reader.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This study is a simulation and experimental research and aimed to investigate the capability and performance of the UHF RFID tag embeddable in small metal cavity to identify and locate distribution transformer status. The research framework of this study is illustrated in Figure 3.1.

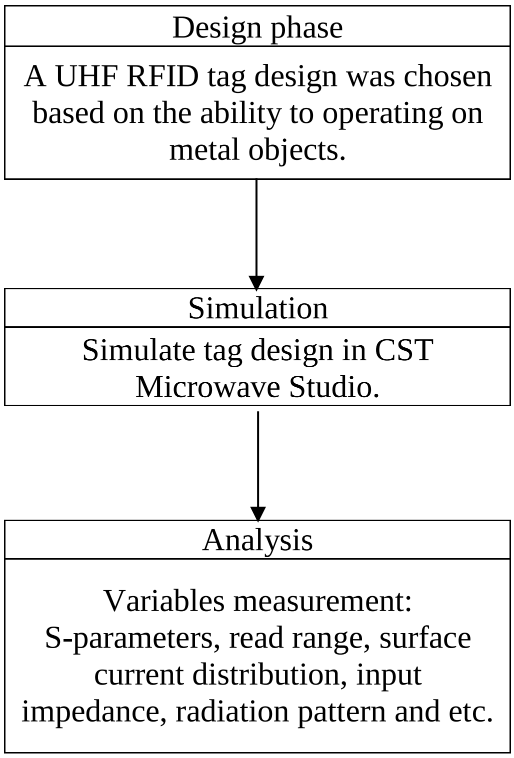

Figure 3.1: Research framework

In this paper the simulation of the UHF RFID was done in CST Microwave Studio which has been widely used in many industries such as electrical and electronics, automotive, aerospace and etc. This kind of computer simulation technology is very useful to replace prototypes in virtual models to study the design and identify its working functions or problems at early design and development stage. In the same time, it can reduce the time and cost incurred before constructing a number of real physical models.

3.2 Design phase

The UHF RFID design proposed in this paper has been designed from a microstrip patch antenna and consists of two rectangular Planar Inverted-F Antennas (PIFAs) as a radiating element which has been epitomized a compact solution to achieve satisfactory performance in terms of gain. The layout and it measurement parameters of the proposed tag is shown in Figure 3.2 and listed in Table 3.2. Full measurement details of the tag attached in Appendix A.

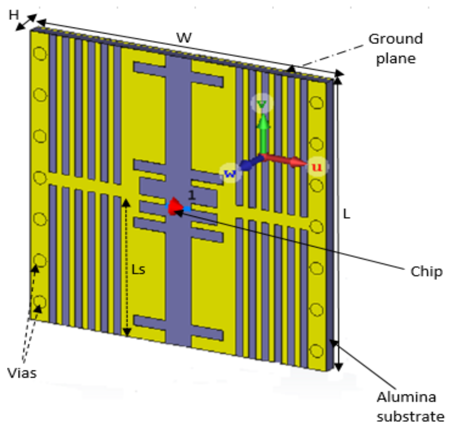

Figure 3.2: Structure of the proposed UHF RFID in free space

Table 3.2: Measurement parameters of UHF RFID

Parameter	Description	Value
L	Length	23 mm
W	Width	23 mm
Ls	Lateral Slit Length	11 mm
H	Thickness	1 mm

The rectangular patch has been designed on a 1 mm thick alumina (Al_2O_3) substrate with relative dielectric permittivity, ε_r = 9 and dissipation factor, tanδ = 0.0003. A number of vias have been placed in between of the top layer and the ground plane to reduce the effect of the lateral metal walls when the tag placed in metal cavity. The tag input impedance is ohmic inductive, when the tag resonating edge is slightly lower than 433 MHz, considering that 866 MHz being the equivalent waveguide wavelength. "To match with the ohmics capacitive input impedance of the UHF RFID chip in this analysis, an EPC global Class-1 Gen-2 Higgs 4 IC (package SOT323) chip manufactured by Alien Technology has been deliberated. Specifically, the chip impedance at the ETSI UHF RFID central frequency (i.e., 866 MHz) is Z_{IC} = 20.55 –

j191.25” (Franchina *et al.*, no date). The structure of the tag was optimized to be embedded and filled with commercial epoxy resin EP46HT (ε_r = 4.8 and tanδ = 0.015) in a $25 \times 25 \times 2.5$ mm^3 cavity carved out of metal plate ($150 \times 150 \times 7$ mm^3). The 3-D dimensions layout of tag in the metal cavity is shown in Figure 3.2.1.

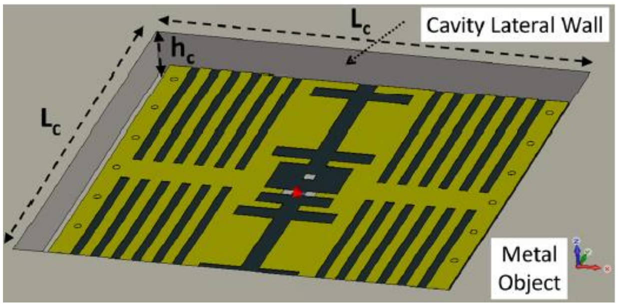

Figure 3.2.1: Layout of tag in metal cavity.

Referring to the design of the tag, the multiple meander slots was utilize to effectively tune the input impedance of the tag with the chip. In a research (Xuan, Lv and Li, 2016), by increasing the number of meanders, the distance of reflection coefficients become closer between the 3 simulated same sized antenna with different quantity of meanders resulted to more offset coupling. Therefore as a conclusion, by adjusting the number of meander slots, the conjugate impedance matching with different microchips can be easily figured out. As in Yang *et al.* (2011) , the serrated multiple slots are also useful to lower the resonant frequency of the designed tag at low UHF range. The distances between the slots were fix at 0.5 mm because wider slots could jeopardize the realized gain in a faster way. Additionally, by increasing the number of slots to the tag causes the inductance to increase and simultaneously decrease the tag capacitance (Bong *et al.*, 2017).

3.3 Simulation

After designing 3D model of tag in CST Microwave Studio the structure was set to be meshed with tetrahedral mesh optimization to simulate the design with high quality performance and high sensitivity as shown in Figure 3.3.

Based on the mesh settings in the software, the structure of the tag are simulated to view the excitation of the current distribution in electric field (E-field) and magnetic field (H-field) view which are shown in Figure 3.4 and 3.5 respectively

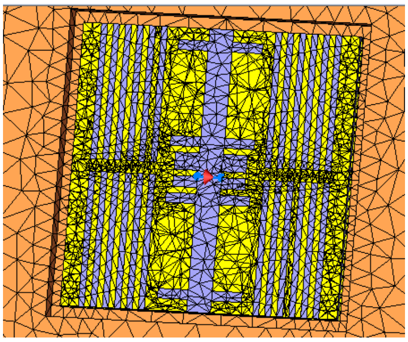

Figure 3.3: Tetahedral mesh view of RFID tag in CST Studio Microwave with 40,587 meshes cell.

.

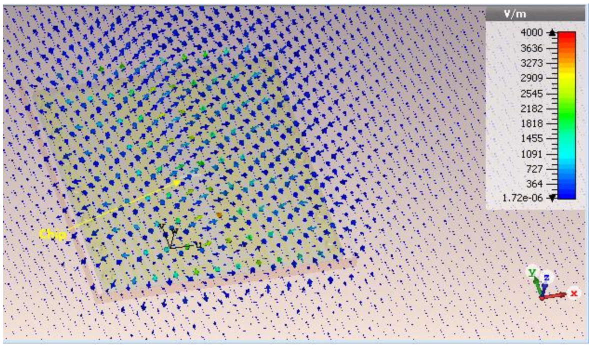

Figure 3.4: Electric field distribution at 866 MHz

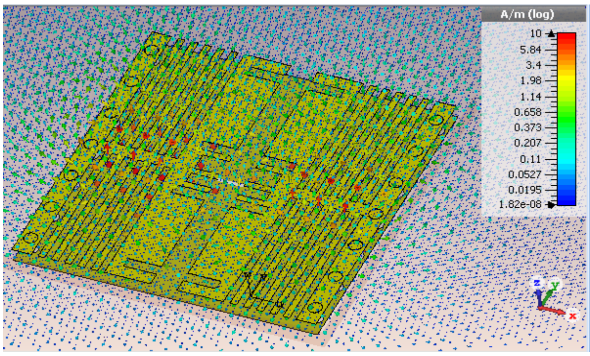

Figure 3.5: Surface current field distribution at 866 MHz

The surface current density in shown in as in Figure 3.4 show the serration of the meander causes the tag perimeter to become longer and the surface current to take a longer path around the tag. The current distributed symmetrically along the slits of the tag and same direction coupled currents at both sides. In Figure 3.5, the current distributed in the H – field along the edge of the tag's radiator where the vias connected to the ground plane to reduce the tag's performance degradation if place on near metal object.

CHAPTER 4

RESULTS , ANALYSIS AND DISCUSSIONS

4.1 Introduction

This section describes the experimental results of the UHF RFID tag simulated in CST Microwave Studio®. The simulation was carried out to ensure the performance of the tag and its parameters to achieve the objectives of this paper has been presented. The overall result focus on to measure the tag's parameters and to discuss the findings obtained through simulation data analyses.

4.2 Results

4.2.1 Impedance matching

Impedance matching in designing UHF RFID tag is very crucial because the microchip attached has a high quality factor which has small resistance and large capacitive reactance at its terminals. A poor impedance match will resulted in less power delivered from the reader to the RFID IC and the read range will reduced. A well-known facts that the gain, the resonant frequency and the input impedance can be effected by nearby conducting and non-conducting object and also effected by the substrate material properties.

From the research by Rao et. Al (2005) the equivalent circuit of chip and antenna in Figure 2.3, the relationship between Z_a , antenna impedance and Z_c , chip impedance can be expressed in the equations as follows:

$$Z_c = R_c + jX_c \tag{1}$$

$$Z_a = R_a + jX_a \tag{2}$$

Where R_c and R_a are the chip and tag resistance respectively, X_c and X_a are the chip and tag reactance respectively.

The voltage supply V_a is an open circuit radiofrequency (RF) voltage developed on the terminals of the tag antenna from the reader antenna's interrogating electromagnetic field.

The chip's impedance Z_c can vary with the power absorbed by the chip P_c and includes energy sapping effects. P_c can be expressed in the terms of maximum available power received from the antenna P_a and power transmission coefficient τ as follows in (3).

$$P_c = P_a \cdot \tau \quad (3)$$

Where τ describes the degree of impedance match between the tag chip and antenna is given by the expression (4).

$$\tau = \frac{4R_c R_a}{|Z_c + Z_a|^2} \quad (4)$$

The ideal complex conjugate impedance match between tag and chip is when $\tau = 1$. The closer τ to 1, the better the impedance match of the tag and chip. For a particular combination $\tau = 1$, a condition of $Z_c = Z_a$ must be achieved which is hard to be realised. Additionally, the antenna is typically matched to minimum threshold power (P_{th}) point in order for the chip to activate.

Thus, the proposed tag was simulated in free space conditions to measure its input impedance as shown in Figure 4.2 when tag embedded in metal cavities and covered in epoxy resin.

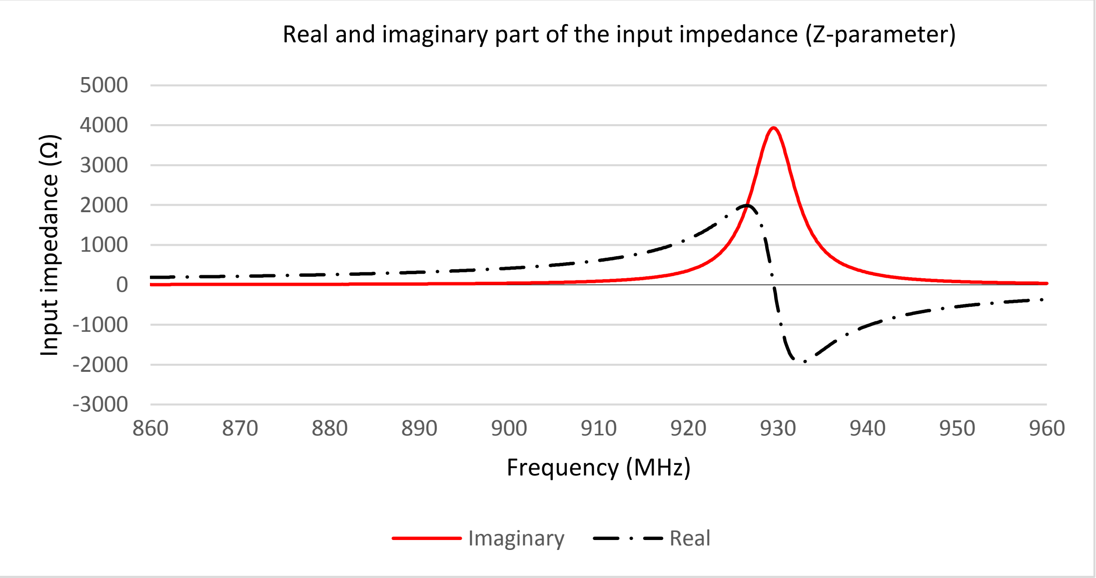

Figure 4.2: Real and Imaginary input impedance of proposed UHF RFID tag.

Based on the Figure , the simulated input impedance is plotted as a function of the frequency and the result shown at the ETSI UHF RFID central frequency, the simulated input impedance is Zin= 10.3 + j189 Ω .

4.2.2 S - parameter

In practice, S-parameter or return loss can described as the input-output relationship of a radar communication signal which in this paper it represents how much power is reflected from the tag and also known as reflection coefficient. In a case where S11 parameter measured on an antenna equals to 0 dB, it means that all power is reflected from the antenna and nothing is radiated. The S parameter plotted in Figure 4.2.1 shown that the designed tag radiates best at 866 MHz, where S11= -7.2 dB. Furthermore, a return loss of -7.2 dB means that the reflected wave is 7.2 dB lower than the incident wave.

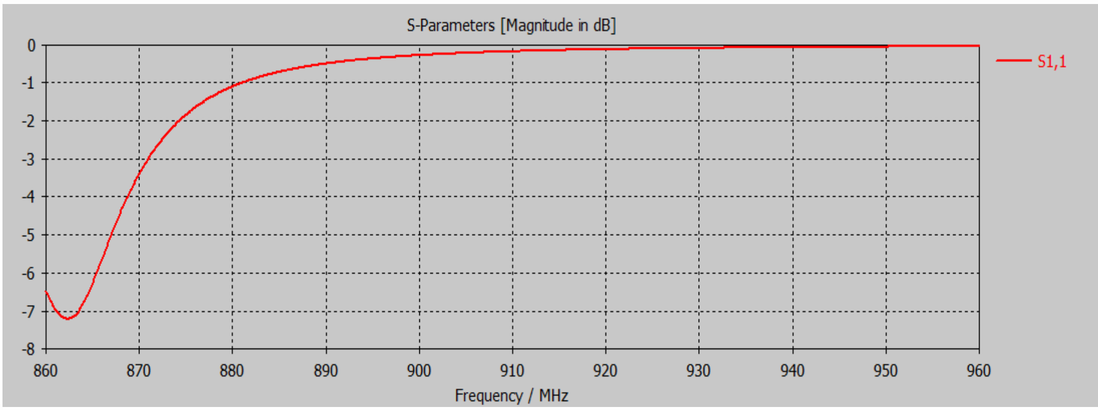

Figure 4.2.1: Plotted S parameter of UHF RFID tag when epoxy is applied.

Additionally, in the figure also shown that at 910 MHz, as the S11 parameter is close to 0 dB, the tag will radiate virtually nothing. If the tag bandwidth is defined as the frequency range where the S11 to be less than -6 dB, then the bandwidth would be roughly 6 MHz, where 866.55 MHz the high end and 859.33 MHz the low end of the frequency band.

4.2.3 Gain & realized gain

The concept of UHF RFID tag power gain or simply gain can be described as a key performance which combines the tag's directivity and electrical efficiency. In this case, the measured gain describes the tag's power output measured against the power input to the tag. But, according to the IEEE standard, the term 'realized gain' is used to differentiate the gain of an antenna because gain does not includes losses arising from impedance mismatches (reflection losses) by considering the total efficiency of the tag along with its directivity. In Figure 4.2.2, shown from the simulated 3-D model of the tag, the maximum realized gain achieved is - 17.3 dB.at central frequency 866 MHz. In Figure 4.2.3, shows the plotted maximum realized gain of designed tag when simulated with epoxy and without epoxy over frequency on Cartesian coordinate system.

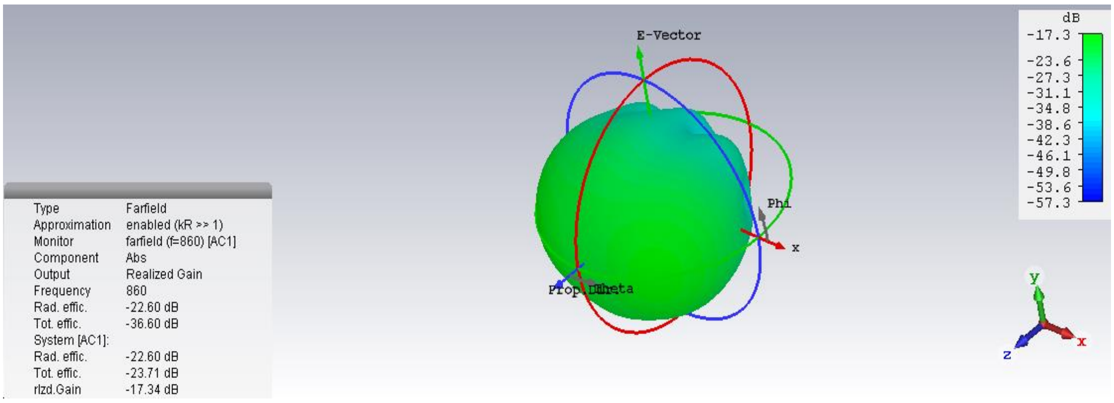

Figure 4.2.2: Simulated realized gain in (θ = 0°) direction as a function of the frequency when the tag placed inside of 25 × 25 × 2.5 mm^3 metal cavity and covered in epoxy resin.

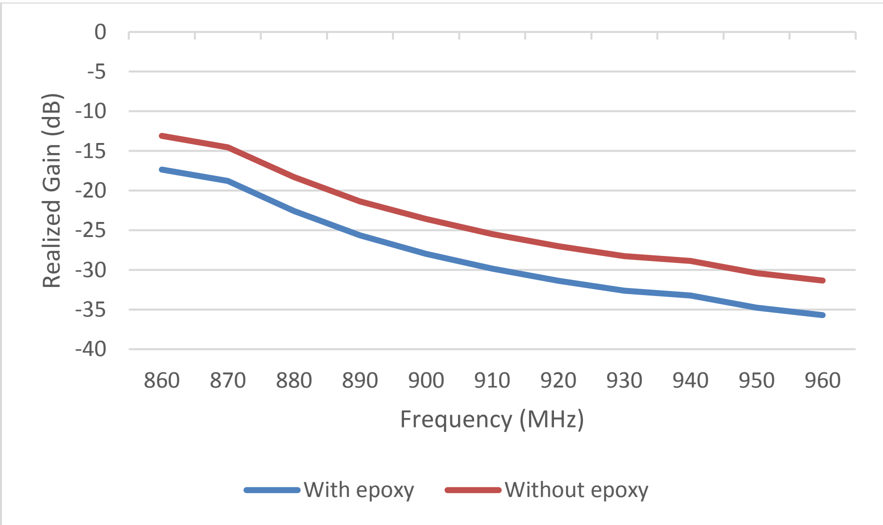

Figure 4.2.3: Plotted realized gain over frequency in θ = 0° direction simulated in condition with epoxy and without epoxy.

4.2.4 Radiation pattern

In the field of EM design, the term radiation pattern or far-field pattern refers to the diagrammatical representations of the distribution of radiated energy as a function of directional or angular dependence. The 3D radiation pattern of the tag shown in Figure 4.2.2. The radiation pattern scanning along XZ – plane (θ = 0°) and YZ – plane (θ = 90°) illustrated in Figure 4.2.4 (a) and (b) respectively.

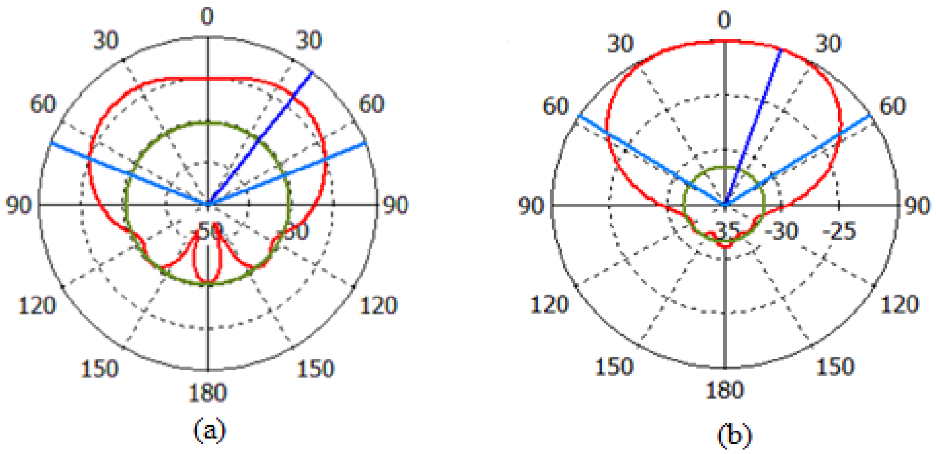

Figure 4.2.4: a) radiation pattern scanning along XZ – plane (θ = 0°) b) radiation pattern scanning along YZ – plane (θ = 90°).

4.2.5 Directivity

The directivity of an antenna is defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all direction". "The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied", the directivity of a non-isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source". Therefore, directivity can be defined in simplified mathematical formula:

$$D = \frac{U}{U_o} = \frac{4\pi U}{P_{rad}} \qquad (5)$$

Where:

$U = r^2 \times W_{rad}$ – radiation intensity

$U_o = \frac{P_{rad}}{4\pi}$ – radiation intensity of an isotropic source

r – distance

P_{rad} – total radiated power

Since directivity is strongly depends on the radiation intensity (U) , maximum directivity of an antenna or RFID tag can be defined as:

$$D_{max} = D_o = \frac{U_{max}}{U_o} = \frac{4\pi U_{max}}{P_{rad}} \quad (6)$$

From the simulated 3D design in CST Microwave Studio, directivity of the designed tag can be defined at farfield result at centre frequency (f=866 MHz) as shown in Figure 4.2.5 and its polar .

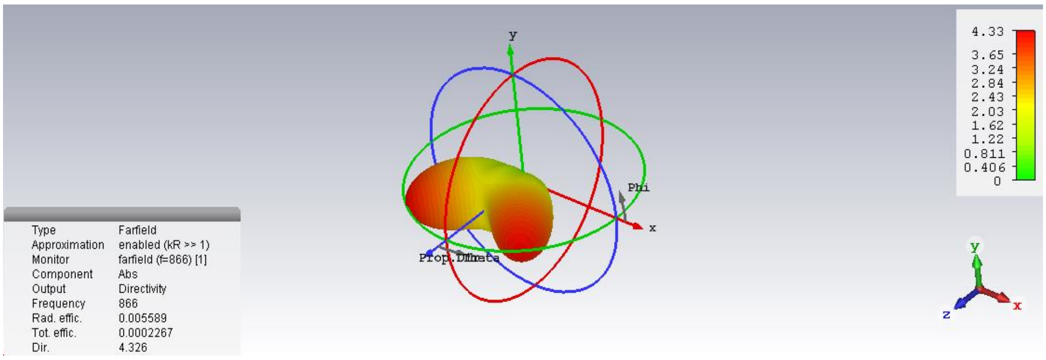

Figure 4.2.5: 3D plot of directivity result UHF RFID antenna at 866 MHz.

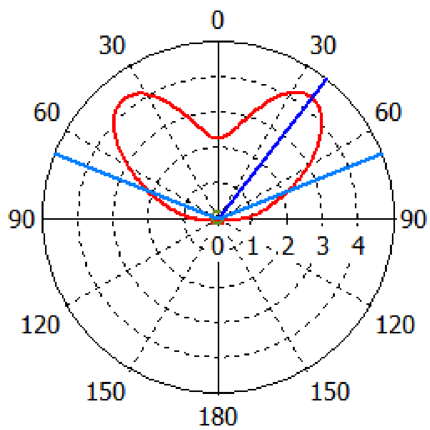

Figure 4.2.5: Plotted directivity result of UHF RFID antenna at 866 MHz on cartesian plane .

From this part of simulation , the tag has directivity of 4.32 dBi and maximum directivity with 3dB angular width is at 38° and 137°.

4.3 Read range

The read range of the antenna is related with: a) the maximum distances which the tag receives the minimum threshold power to turn on the tag and scatter a signal back, b) the maximum distances at which the tag can detect the return signal from the reader.

Generally, the maximum distance at which the reader can detect a return signal high is far greater than the maximum distance the tag can receive (Pth) to turn on and scatter back. Additionally, it is easy to adjust the power settings or the antenna of the reader system to ensure that this is always the case. Thus, for this work the read range will be considered the maximum distance at which the tag can receive the minimum threshold power (Pth) required to turn on and scatter a signal back.

In free space, the power received from the antenna P_a can be derived from the Friis Equation.

$$P_a = P_r \; G_r \; G_a \left(\frac{\lambda}{4\pi r}\right)^2 \qquad (7)$$

Where:

P_r - power transmitted by the reader,

G_r - reader gain antenna

G_a - gain of tag

λ - wavelength,

r - the distance between the tag and reader.

Equation (7) can be simplified to find the maximum read range of the antenna receiving the minimum threshold power as follows:

$$r = \frac{\lambda}{4\pi} \times \sqrt{\frac{P_r \; G_r \; G_a \; \tau}{P_{th}}} \qquad (8)$$

The multiplication of equation (8) can be easier calculated by changing the multiplication of power transmitted by the reader and reader of gain antenna , ($P_r \, . \, G_r$) which can be defined as another parameter of “Equivalent Isotropic Radiated Power (EIRP), the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum gain of an antenna” (Leong, 2008). EIRP is commonly given in decibel value.

Based on the formula in, with the gained information in reader's datasheet (Inpinj Speedway R420 reader) datasheet and class-1 Gen-2 Higgs 4 IC chip datasheet, the expected read range of the UHF RFID tag is 1 meter. The 1.02 meter maximum read range achieved in simulation result from CST Microwave Studio shown in Figure 4.3 proved the approximation read range value with the calculated value.

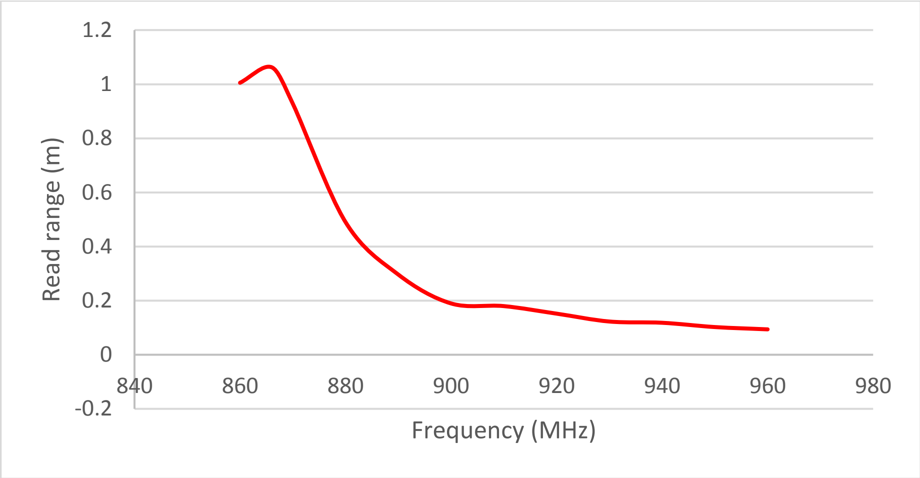

Figure 4.3 : The read range over frequency of UHF RFID tag placed in a 25×25×2.5 mm^3 cavity realized on a metal plate (150×150×7 mm^3) and covered by an epoxy resin.

Furthermore, to measure the effect of removing epoxy resin on the read range of RFID tag in the metal cavity, a simulation was conducted and the result shown as in Figure 4.3.1. The maximum read range of the tag drops to almost 60 cm to only 40 cm read range to the reader.

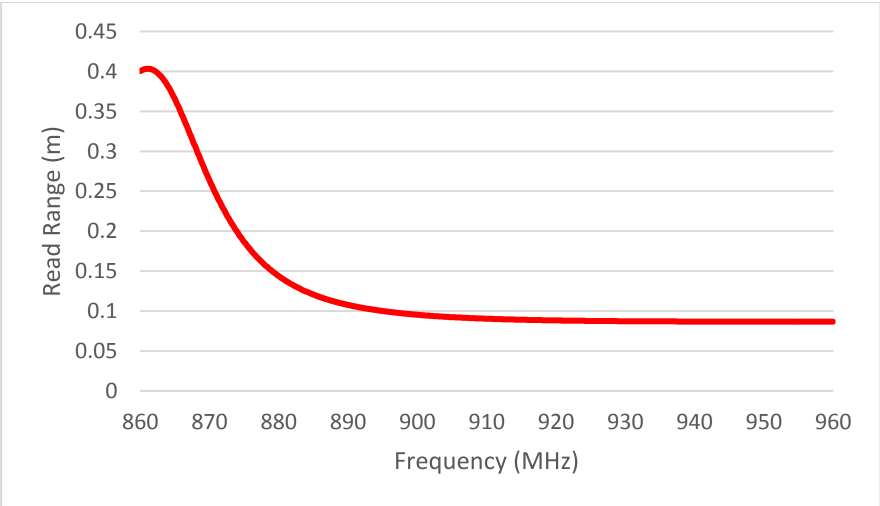

Figure 4.3.1: Read range of RFID tag when the epoxy resin layer on tag removed.

4.4 Summary

Based on the simulated 3D model in CST Studio Microwave , the results and parameters received it is proved that the proposed tag consists of two rectangular Planar Inverted-F Antennas can work well when embedded in metal cavity covered with epoxy resin layer.

The 3D model need to be designed properly up to micrometer scale and meshed in details to get a high accuracy result. The radius of vias located at both side of the tag cannot be smaller than 0.25 mm because it will be hard to mesh and identified as low quality elements in the computer software.

The performance of the tag are highly depend on the impedance matching of the chip and antenna. The gain of the tag plays a big role to ensure the tag will have a high return loss. Read range measurements were calculated based on the reader datasheet Inpinj Speedway R420 with Ptx, EIRP value = 3.28W. The calculated and simulated read range when the tag is placed inside a cavity and covered by the epoxy resin is match approximately about 1m. It is lower than the estimated one mainly due to uncertainty in the epoxy resin thickness, approximately same result got in (Franchina *et al.*, no date).

A simulation was also conducted to investigate the effect of placing the tag only in the metal plate by removing the epoxy resin layer on top. The result shown that, the read range of the tag reduced to only 40 cm. The experimental test result can be conclude in Table 4.4 below.

Table 4.4: Experimental test result of UHF RFID tag embedded in metal cavity with and without epoxy resin layer.

Setup	**Measured maximum read range**
Tag in metal (without resin)	0.4 m
Tag in metal (with resin)	1 m

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The purpose of this study is to investigate the performance and ability of the designed Radio Frequency Identification tag operating in Ultra High Frequency band to remotely track metal components i.e distribution transformer. Simulation of the RFID tag was done in CST Microwave Studio to measure its performance such as gain, radiation pattern, working bandwidth, input impedance and etc.

Firstly, the 3D model of the designed tag illustrated in the free space of the software and render the structure in with mesh settings for physical simulations from a subdivision of a continuous geometric space into discrete geometric and topological cells. Secondly, the numerical analysis will be described by using Maxwell’s equation to solve the experiment in frequency domain.

In conclusion, the designed RFID tag has a good performance to be realised and implemented to achieve the stated objectives. The read range achieved when placed in metal cavity and covered with epoxy resin is 1 meter and 0.4 meter reading range is achieved if the epoxy resin is removed. The realized gain related to the geometric design structure achieved from the simulation is -17.3 dB at central frequency of 866 MHz. The maximum read range of the tag is 1 meter. The maximum high gain of the tag will be achieved if the reader located at the angle of 38° and 137° from the tag.

5.2 Recommendations for future work

This thesis provides some practical solutions specifically to tag and identify metal components. However, due to time constraint and limitation of resources by the set duration of this research some ideas for improving the solutions in terms of performance, cost and efficiency were not able to be carried out.

They are listed as follows:

a) Research on the security of information keep in the tag design

The tag introduced in this paper is designed to keep the data of manufacturing data which is crucial and important to be keep at safe. Future work can be done to make a research of how to create a security level to prevent the data saved from changed by unauthorised person.

b) Lifecycle and reliability of the tag

Since the proposed tag will be used to keep tracking or any important data, it is necessary to know the expected reliability and life cycle of the tag itself because basically a manufacturing data need to be keep in 3 years before the data can be dispose.

c) Comparing the performance of chip with other UHF RFID design

In the research the geometric scale effect are not considered. For future work, the performance of the chip class-1 Gen-2 Higgs 4 IC (package SOT323) manufactured by alien Technology could be compared with other design of UHF RFID tag antenna, so that the impedance matching of the chip and antenna could be studied in more details.

REFERENCES

A. A. Babar, T. Bjorninen, V. A. Bhagavati, L. Sydanheimo, P. Kallio and L. Ukkonen, "Small and Flexible Metal Mountable Passive UHF RFID Tag on High-Dielectric Polymer-Ceramic Composite Substrate," in IEEE Antennas and Wireless Propagation Letters, vol. 11, pp. 1319-1322, 2012.

Alien Technology. Higgs 4 Chip Datasheet. Accessed: April. 6, 2019.[Online]. Available: http://www.alientechnology.com/products/ic/higgs-4/

Bong, F. *et al.* (2017) 'Miniaturized Dipolar Patch Antenna With Narrow Meandered Slotline for UHF Tag', 65(9), pp. 4435–4442.

Finkenzeller, K. (2003) *Fundamentals and applications in contactless smart cards, radio frequency identification and near-field communication*.

Franchina, V. *et al.* (no date) 'Compact In-metal UHF RFID Tag for Manufactured Metallic Components', *2018 3rd International Conference on Smart and Sustainable Technologies (SpliTech)*. University of Split, FESB, pp. 1–5.

Hu, Z. (2010) 'Solutions for Hard-to-Tag Objects in UHF RFID Systems', *Electronic Engineering*, (September).

K.~S.~Rao, P.~V.~Nikitin and S.~F.~Lam (2015) 'Antenna design for UHF RFID tags: A review and a practical application', *IEEE Transactions on antennas and propagation*, 53(12), pp. 3870–3876.

Kim, S. Y. *et al.* (2009) 'A study on control method to reduce collisions and interferences between multiple RFID readers and RFID tag', *Proceedings - 2009 International Conference on New Trends in Information and Service Science, NISS 2009*. IEEE, (February 2005), pp. 339–343. doi: 10.1109/NISS.2009.231.

Konishi, T. *et al.* (2009) 'An impedance matching technique of a UHF-band RFID tag on a high-impedance surface with parasite elements', *RWS 2009 IEEE Radio and Wireless Symposium, Proceedings*. IEEE, pp. 67–70. doi: 10.1109/RWS.2009.4957286.

Lechner, J. *et al.* (2016) 'Concept for an intelligent UHF RFID reader according to the Ideas of Industry 4.0', *Proceedings of Smart SysTech 2016 European Conference on Smart Objects, Systems and Technologies*, pp. 3–7.

Leong, K. S. (2008) 'Antenna Positioning Analysis and Dual-Frequency Antenna Design of High Frequency Ratio for Advanced', (January).

Nikitin, P. V. and Rao, K. V. S. (2006) 'Theory and measurement of backscattering from RFID tags', *IEEE Antennas and Propagation Magazine*. IEEE, 48(6), pp. 212–218. doi: 10.1109/MAP.2006.323323.

Prothro, J. T., Durgin, G. D. and Griffin, J. D. (2006) 'The Effects of a Metal Ground Plane on RFID Tag Antennas', *2006 IEEE Antennas and Propagation Society International Symposium*. IEEE, pp. 3241–3244. doi: 10.1109/aps.2006.1711302.

Xuan, X., Lv, L. and Li, K. (2016) 'A Miniaturized Meandered Dipole UHF RFID Tag Antenna for Flexible Application', *International Journal of Antennas and Propagation*, 2016, pp. 1–7. doi: 10.1155/2016/2951659.

Yang, P. H. *et al.* (2011) 'Compact metallic RFID tag antennas with a loop-fed method', *IEEE Transactions on Antennas and Propagation*. IEEE, 59(12), pp. 4454–4462. doi: 10.1109/TAP.2011.2165484.

Zheng, Z. . and Zhang, T. . (2012) 'We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %', *School of Enviromental Sciences*.

APPENDICES

APPENDIX A: Measurement details of UHF RFID tag.