DESIGN OF ANTENNA FOR UHF RFID APPLICATION

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by

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LIST OF ABBREVIATIONS

AUT	Antenna under test
CST	Computer Simulation Technology
EM	Electromagnetic
FR-4	Fire Retardant
MW	Microwave
PCB	Printed Circuit Board
RF	Radio Frequency
RFID	Radio Frequency Identification
UHF	Ultra-High Frequency

LIST OF SYMBOLS

M_L	Antenna loss due to impedance
ε_R	Antenna radiation efficiency
ρ	Complex reflection coefficient
D	Directivity
G	Gain
$tan\ \delta$	Loss tangent of dielectric
f_L	Lower frequency
U_m	Maximum radiation
P_{in}	Power incident
P	Power radiation
r	Radial Distance
ε_r	Relative Dielectric Constant
S_{11}	Return loss
h	Substrate Thickness
ε_T	Total antenna efficiency
f_H	Upper frequency
λ	Wavelength
TM_x	X-component Transverse magnetic modes

REKABENTUK ANTENA UNTUK APLIKASI PENGENALAN FREKUENSI RADIO (RFID) UHF

ABSTRAK

Dalam beberapa dekad yang telah dilalui, permintaan untuk Aplikasi Pengenalan Frequensi Radio (RFID) semakin meningkat dan sistem ini menawarkan prestasi yang lebih baik dalam pelbagai bidang pengguna dan industri sepertinya penggunaan pengenalan automatik dan pengesanan objek. Pada keadaan semasa, pilihan frekuensi utama yang digunakan dalam sistem RFID ialah jalur frekuensi ultra tinggi (UHF) untuk bacaan kelajuan tinggi dan data kapasiti yang tinggi. Walau bagaimanapun, terdapat banyak tag antena UHF RFID tidak dioptimumkan untuk reka bentuk yang padat. Berasaskan reka bentuk antena dahulu, terdapat beberapa reka bentuk yang mempunyai kelemahan sebab kesan bidang pinggiran yang lemah dan tidak mampu menyelesaikan kesan sisihan frekuensi dalam sistem UHF RFID Eropah selepas fabrikasi. Oleh itu, projek ini mencadangkan reka bentuk tag ubahsuai dengan mengunakan antena struktur gelung dwikutub lipat padat dengan elemen parasit segmen E. Tag antena cadangan ini digunakan dalam sistem Malaysia UHF RFID iaitu dari 919 MHz hingga 923 MHz dan saiz yang mempunyai 35 * 35 mm^2 dengan menggunakan FR-4 sebagai substrat. Sisihan frekuensi disebabkan oleh nilai toleransi dalam fabrikasi PCB antena telah diatasi dengan mengubahkan parameter elemen parasit. Reka bentuk antena tag ini dihantarkan untuk fabrikasi PCB sebagai prototaip untuk pengesahsahihan prestasi dan keputusan. Keputusan ukuran yang mempunyai lebar jalur iaitu 11 MHz (915.5 - 926.5 MHz) dan kehilangan balik S_{11} yang mempunyai -17.67 dB pada 921 MHz telah ditunjukan. Ukuran maxima gandaan ialah -4.77 dB pada 921 MHz. Secara keseluruhannya, tag antena yang dicadangkan menunjukkan persetujuan yang baik antara keputusan pengukuran dengan keputusan simulasi dan mempunyai jarak jalur yang besar.

DESIGN OF ANTENNA FOR UHF RFID APPLICATION

ABSTRACT

For the past decades, the demand for the radio frequency identification (RFID) system has increased and this system offered a better performance in numerous consumer and industrial fields such as the application of automatic identification and object tracking. Recently, the preferred frequency band used in the RFID system is the ultra-high frequency (UHF) band as it has high-speed reading and high data capacity. However, most of the UHF RFID tag antenna are not optimised for its compactness. Based the previous antenna designs, some are found to have flaws due to the weaken fringing field effect and their inability to settle the effect of frequency deviation in Europe UHF RFID system after fabrication. Therefore, this project proposed a modified compact tag antenna design by using folded dipole loop structure with E-segment parasitic element. This proposed tag antenna is used in Malaysia UHF RFID system which is from 919 MHz to 923 MHz and it has dimension of 35 * 35 mm^2, using FR-4 as substrate. The frequency deviation caused by the tolerance value in the PCB fabrication is solved by adjusting the parameters of parasitic element. The tag antenna is sent for the PCB fabrication as a prototype to validate the performances and results. The measurement results show the bandwidth has 11 MHz (915.5 - 926.5 MHz) and the return loss $\boldsymbol{S_{11}}$ of -17.67 dB at 921 MHz. The radiation pattern of both E-plane and H-plane have dipole-shaped pattern and it has maximum measured gain is -4.77 dB at 921 MHz. Overall, the proposed tag antenna shows good agreement between measurement results and simulation results, and has large frequency range.

CHAPTER 1
INTRODUCTION

1.1 Research Background

Radio Frequency Identification (RFID) uses radio frequency (RF) signals to identify a tagged object in a non-contact manner. It is used to overcome the limitation of the barcodes technology (Lotlikar *et al.*, 2013). Compared to barcodes technology, the requirement for an object to be within its line of sight is not needed. The RFID tag can be embedded in an item which is to be detected by the RF signal. This means RFID technology avoids the physical exposure to the detection by the scanner. In addition, long read range can be achieved with RFID technology and multiple tag reading is supported in RFID systems. Therefore, the advantages of RFID technology over barcodes technology are summarized in points below (Kaur *et al.*, 2011):

- Line of sight (LOS) is no longer needed by RFID system.
- The ability of reprogramming and high data capacity can be achieved by RFID system.
- The application in harsh environment, particularly in unfavorable moisture, temperature and chemical condition is possible with RFID system.

Thus, the speed of numerous processes in diverse consumers and industries are increased by the RFID technology (Senadeera and Dogan, 2016). A groundbreaking path to countless novel applications of RFID is opened by the state-of-the-art technological expansions in several productions. The progress is kept at a fast pace in the next coming decades. The current applications and research priorities of RFID in various fields are shown in Table 1.1.

Table 1.1: Applications and research priorities of RFID in different fields (Resource and Report, 2009)

		Research Priorities		
		Smart miniaturized devices with advanced functionality and performance	**Autonomously operating power efficient and networked smart devices**	**Robust systems compactible and adaptive to environment and lifetime requirements**
Application – Wireless Identifiable Smart System	Aeronautics	Passenger and luggage	Function monitoring RFID devices	Engine and parts service and maintenance
	Automotive	Operator control ITS	RFID and tire pressure	Engine and motor monitoring service maintenance
	Telecom	NFC	RFID ubiquitous sensor nodes	Multi standards EX
	Medical	Physiological parameter monitoring ban	Equipment personal RTLs	Implantable RFID system In Vivo
	Retail and Logistic	D-Pack C-Pack	Transport RTLs and positioning	Harsh Environment Logistics
	Safe Security Privacy	Access control	Environment surveillance	Active tamper protection

There are many types of antennas have been applied to RFID system. The microstrip patch antenna is preferred compared to conventional microwave antenna for the RFID system because it is cheap for manufacture, integrated passives and almost any surface such as planar, non-planar, and rigid exterior can be mounted (Kwa, Qing and Chen, 2008). The flexibility of fabrication and simultaneous fabrication of feed lines is possible with the microstrip patch antenna. The matching network of the microstrip patch antenna can be achieved by the microstrip patch antenna. Finally, the fabrication time by microstrip patch antenna can be reduced compared to conventional microwave antenna (Singh and Tripathi, 2011).

1.2 Problem Statement

There are two research problems. First. the minimization of the products demands the need of compact RFID system to track the small size items, such as gadget, mechanical parts, medical item and electronic components (Wang, 2015). The problem of the lower frequency band like high frequency (HF) band antenna and low frequency (LF) band is unable to integrate with small items due to large electrical size of their antennas. The electrical size of the antenna is inversely proportional to the frequency applied by the antenna. Therefore, the compact size of the antenna is required to cope with the current situation faced by the industry and consumer (Lai, Xie and Cen, 2013b). The higher frequency band UHF is used to solve the problems as it can further minimize the size of the antenna and provides long read range.

The second research problem is there are a lot of UHF RFID tag antenna designs that are not compact. Previously, the size of 184 x 172 mm^2 (Shrestha, Elsherbeni and Ukkonen, 2011) and smaller design of 72.3 x 72.3 mm^2 (Borja *et al.*, 2012) UHF RFID antenna are proposed. However, these tag antennas are still not able to be fitted into small items. Therefore, this project is to find out which compact antenna design is the best. The condition for compact design is smaller than or equal to quarter size of the electrical wavelength UHF RFID tag antenna, that is, 40 x 40 mm^2.

1.3 Objectives

This research aims to design a compact RFID tag antenna of 40 x 40 mm^2 to achieve quarter size reduction of typical UHF antenna and this antenna can be operated at Malaysia UHF RFID system (919 - 923 MHz) (MCMC, 2005). The specific objectives of this research are as follows:

(a) To design a compact tag antenna for Malaysia UHF RFID system, from 919 MHz to 923 MHz.

(b) To perform a parametric study of the design parameters consideration for the proposed UHF RFID tag antenna.

(c) To validate the design and performance of the proposed UHF RFID tag antenna as a prototype through fabrication.

1.4 Research Scopes

The design process for this project is separated into two main parts: software and hardware. The software part focuses on the process of designing the antenna using the CST MW and ADS momentum. First, the UHF band antenna are designed separately based on their own requirements and characteristics. The hardware part focuses on Printed Circuit Board (PCB) fabrication and component assembly. Upon completing the antenna fabrication, the fabricated antenna is tested and analysed to validate the results and to ensure that all objectives are achieved. The contribution of the design should provide a compact UHF antenna design to tag smaller size items and overcome the weakness of previous antenna designs. The overall scope for the research is illustrated in Figure 1.1.

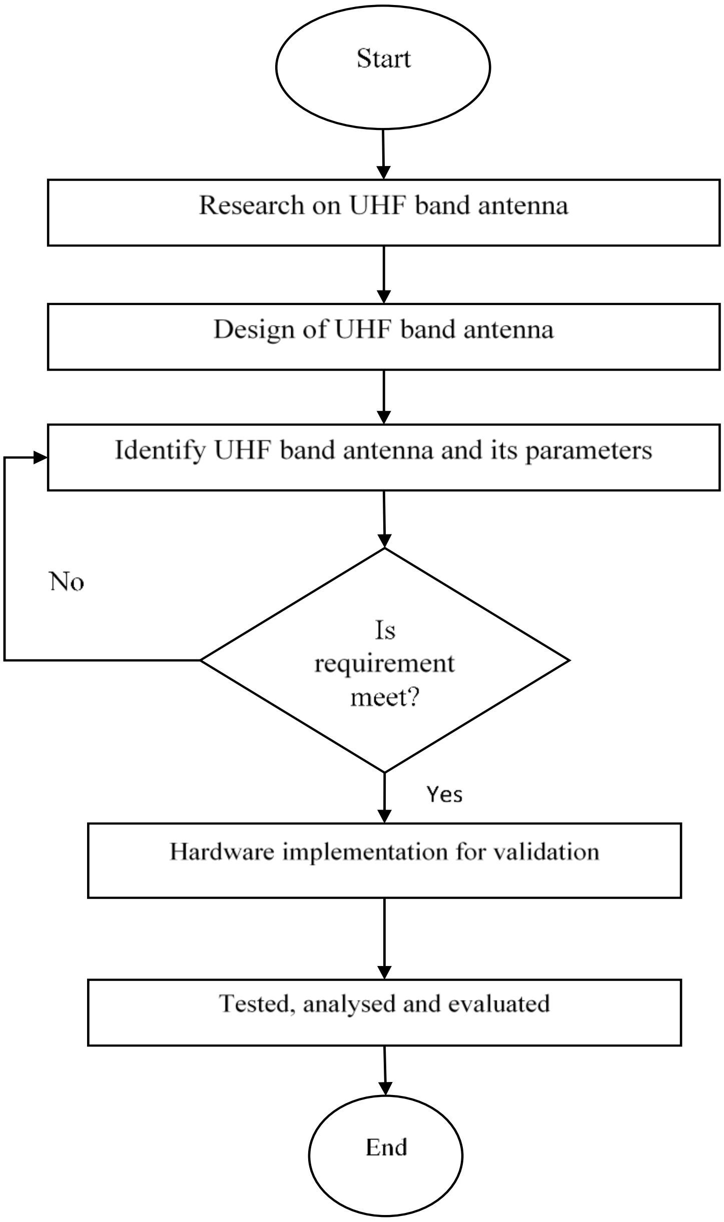


Figure 1.1: Flow chart of overall research scope

1.5 Thesis Outline

This thesis is organized into five chapters. Chapter 1 consists of the Research Background, Problem Statement, Objectives, Requirements, Research Scopes, and Thesis Outline. Chapter 2 deals with introduction of UHF RFID system, principle of tag operation, RFID Operating Frequency and Antenna Parameters. Previous Related Research is also discussed in Chapter 2. Chapter 3 comprises of two major parts. The first part briefs the designation of the tag antenna. The Antenna Research Framework is discussed with the characteristic of substrate and tag antenna requirement. The selection process of designing the UHF RFID tag antenna is discussed followed by explanation of Fabrication of Antenna. The second part brings the methods for hardware implementation, the measurement setup for Return Loss, Radiation Pattern and Gain. Parametric study on the effect of the finalized proposed tag antenna's parameters is discussed in Chapter 3 as well. In Chapter 4, the analysis and discussion of Near-field Magnetic and Surface Current distribution, the comparison of simulation and measurement results of Return Loss, Gain and Antenna Efficiency and Radiation Pattern are discussed. The Conclusion and Future Works for this project are presented in Chapter 5.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

In this chapter, the theory of UHF RFID system, its antenna parameters and the previous works are explained. The introduction of RFID system is described in Section 2.2. The theoretical background and operation of tag antenna and the background of RFID operating frequency are mentioned in Section 2.3, 2.4 and 2.5 respectively. The theory of antenna parameters which are important for simulation and measurement results later are explained Section 2.6. The previous works on compact UHF RFID tag antenna in Section 2.7. The summary of literature review is in Section 2.8.

2.2 Introduction of RFID System

There are two components consist in RFID system: tag and reader. Normally unique identification data contained by tag is to be identified by the reader. When the tagged objects entered the RF field by the reader, the energy is received by its tag from the RF field. After it received sufficient energy, the modulating signal by the tag is resonated to the reader. After that, the modulating signal from the tag is received by the reader, the signal is decoded and then the data from the tag was retrieved by it. Finally, the wireless signal to a specific desired output was converted by decoded signal, such as an analogue current data analysis via computer software (Lotlikar *et al.*, 2013). The general illustration the typical relationship between the tag and the reader is shown in Figure 2.1.

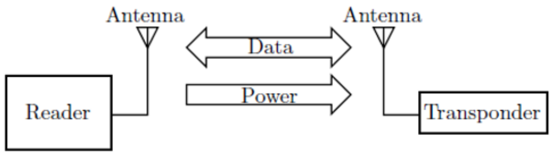


Figure 2.1: Overview of RFID System (Mostafa *et al.*, 2011)

2.3 Tag Antenna

The purpose of the tag antenna is to store a substantial sum of information and to attach to an extensive variety of stuffs for identification and tracking purposes (Chen, 2007). Normally, the RFID tag is categorized into three types: passive, active, and semi-active.

2.3.1 Passive RFID

The power emitted from the reader is used by RFID passive tag to galvanize itself and communicate stored data to the reader. Active power source does not need by it. Compared with active or semi-active tags, passive tags are simpler, lighter and less expensive. The resistant to harsh environmental condition is better and infinite operational lifetime. However, reading distances is short compared to active tags and therefore higher power readers is higher.

From Chen (2007), the tag-to-reader communication operation of a passive tag, the reader always communicates first, followed by the tag. For the passive tag to transmit data the tag reader is necessarily.

2.3.2 Active RFID

Power emitted from the reader for data transmission is not needed by RFID active tag because the on-board power source is available by the tag itself. Either reader or tag can initiate data communication first without need of proper sequences in active RFID (Chen, 2007). Contrary to the passive tag, it has greater reading distance but it has limited battery life for active operation.

2.3.3 Semi Active RFID

Like active tag, the RFID semi-active tag has an on-board power source to provide energy for its operation. On the contrast, the power emitted from the reader to transmit data is still used by semi-active tag. Therefore, the sequence of the data communication, the reader always communicates first, followed by the tag. The benefit of this semi-active tag over the passive tag is longer reading distance is offered by it because the reader's signal to activate itself by semi-active tag is not required. A good readability may be offered by a semi-active tag for tagging RF-opaque and RF-absorbent materials (Chen, 2007).

2.4 Tag Antenna Operation

Two types of energy coupling mechanisms for interaction between tag and reader are: near-field coupling and far-field coupling. These coupling mechanisms are different due to different electromagnetic (EM) field behaviours in each zone. For example, near-field couplings are applied to the low frequency bands (HF and LF) of RFID systems with short reading distances, whereas far-field couplings are applied to the UHF and Microwave bands of RFID systems with long reading distance.

Of the radian sphere where the inside area is the near-field zone while the outside area is far-field zone as shown in Figure 2.2. The boundary between near-field and far-field is not definite exactly due to changes in the electromagnetic field occur progressively. For near-field operation, the field components have different angular and radial dependence (e.g., $1/_{r^3}$). The near-field region is divided into two sub-regions: radiating and reactive regions. In radiating region, the angular field distribution is dependent on the distance whereas in reactive region, energy is stored but not radiated. For far-field operations, the propagation of electric and magnetic field is outwards as an electromagnetic wave and are perpendicular to each other and to the direction of propagation. Angular field distribution does not depend on the distance from the antenna. The fields are uniquely related to each other via free space impedance and decay as $1/_{r}$ (Nikitin, Rao and Lazar, 2007). The boundary between the near- and far-field zones can be determined given in Equation 2.1.

$$r \geq \frac{2D^2}{\lambda} \tag{2.1}$$

where *D* is the maximum dimension of the radiating structure and *r* is the distance from the antenna (Harvey Lehpamer, 2008).

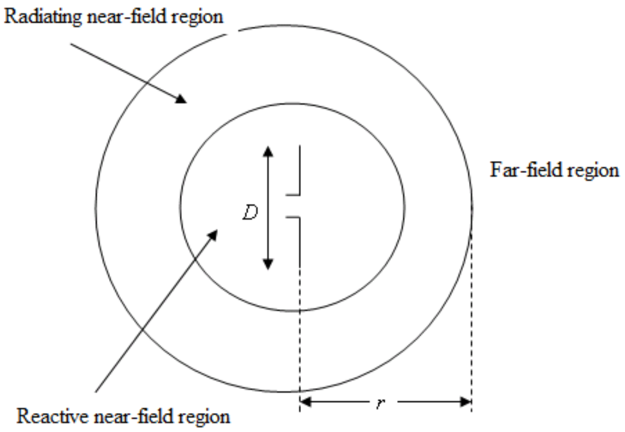


Figure 2.2: Near field zone versus far field zone (Harvey Lehpamer, 2008)

The next section discusses the principle of the near-field and far-field couplings between the tag and the reader.

2.4.1 Near-field Coupling

Electromagnetic field in the near-field zone is reactive and quasi-static by nature. Electric field is decoupled from the magnetic fields. Their domination is determined by the type of the antenna employed. For instance, when a dipole antenna is used, the electric field dominates while a small loop antenna is used, the magnetic field dominates. These couplings may be achieved between the tag and the reader through the interaction with either electric or magnetic fields, namely, inductive and capacitive coupling. Inductive coupling is widely available in near-field RFID systems (Chen, 2007).

For inductive coupling, the operation by the tags are almost passively provides the energy required for the operation by the reader is needed. The coil antenna of the reader generates a strong magnetic field that penetrates the cross section of the coil area and the area around the coil as shown in Figure 2.3. The efficiency of the power transfer between the coil antenna of the reader and the tag is proportional to the operating frequency, the distance between the coil, the number of windings, the area enclosed by the coil antenna, and the angle of the two coil antennas in relation to each other. For a inductive coupling system, the tag can be communicated with the reader by varying the impedance (Chen, 2007).

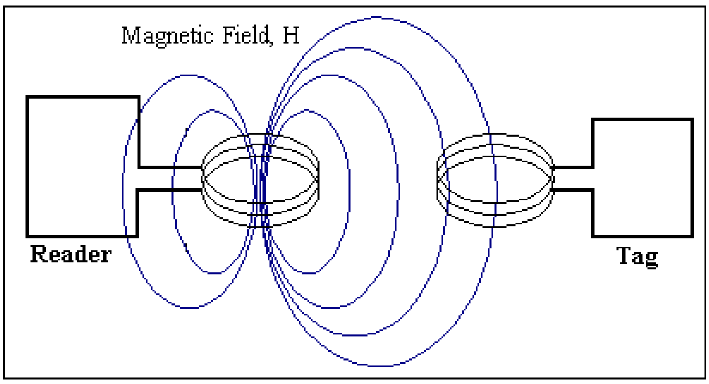


Figure 2.3: Inductive coupling between reader and tag (Finkenzeller, 2005)

For capacitive coupling, the antennas are created and interacted with the quasi-static electric field as shown in Figure 2.4. The field strength and coupling strength are determined by the distribution of charges, not by currents. Capacitive coupling is used fewer compared to inductive coupling because coupling strength is dependent on the amount of accumulated charges. For example, dipole antenna is suitable for capacitive coupling because its electric field dominates the magnetic field. Resonant circuits are required for maximum coupling purposes. Since the antenna has its own capacitance, the inductance is added parallel to the tag and in series to the reader (Chen, 2007).

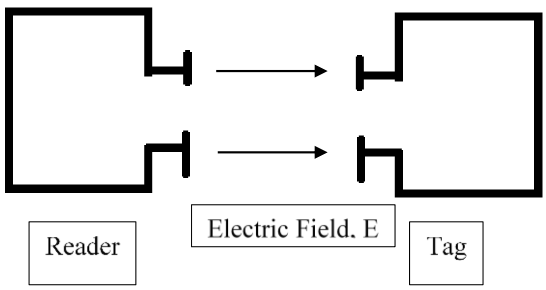


Figure 2.4: Capacitive coupling between reader and tag (Mitsugi, 2009)

2.4.2 Far-field Coupling

The zone outside the near-field region is where the far-field region starts. In far-field RFID systems, the electromagnetic waves radiating captured by the tag from the reader's antenna. Tags in this RFID system are located beyond the near-field zone of the reader and prevent the information from being transmitted back to the reader through load modulation. Therefore, the communication between the tag and the reader in far-field RFID systems uses a different coupling called backscattering (Chen, 2007).

2.5 RFID Operating Frequency

According to Leong *et al.* (2006), the RFID systems can be operated into four common frequency bands:

1. LF band: 125 kHz (ISO 18000-2:2009)
2. HF band: 13.56 MHz (ISO 18000-3:2010)
3. UHF band: 860 MHz to 960 MHz (ISO 18000-6:2013)
4. Microwave band: 2.45 GHz and 5.8 GHz (ISO 18000-4:2008)

UHF band is preferred since the microwave band is still in development, HF band and LF band have poor performance and does not have single worldwide standard (Impinj, 2017). According to Zhang *et al.* (2006), high data transfer rate and broad readable range is achievable by UHF band. Meanwhile, the antenna made by LF bands is too big and slow data rate which causes trouble in following the trend. The comparison between four frequency bands as shown in Table 2.1 (Dressen, 2004; Impinj, 2017):

Table 2.1: Comparison between frequency bands in RFID System (Dressen, 2004; Impinj, 2017)

Frequency Band	**LF**	**HF**	**UHF**	**Microwave**
Common Frequency	135 kHz	13.56 MHz	860 MHz to 960 MHz	2.45 GHz and 5.8 GHz
Coupling	Inductive	Inductive	Backscatter	Backscatter
Communication Range	20 - 100 cm	10 - 70 cm	3 - 10 m	Under development)
Data Rate	Low	High	Very High	Very High
Maturity	Mature	Established	New	Under development

2.6 Antenna Parameters

Several important antenna parameters are used to evaluate the performance of the antenna in the proposed design including return loss, bandwidth, radiation pattern, directivity, and gain. These antenna parameters are discussed in the following section.

2.6.1 Return Loss S_{11}

Return loss is defined as a measure of the effectiveness of power delivery from a transmission line to a load such as the antenna. The power incident on the antenna under test (AUT) is expressed as P_{in} while the power reflected to the source is expressed as P_{ref}. The return loss in decibel unit is defined as shown in Equation 2.2:

$$RL = 10log_{10}\left(\frac{P_{in}}{P_{ref}}\right)\ dB \tag{2.2}$$

The higher the magnitude of return loss, the closer of the circuit match. If the power is expressed in terms of voltage or equivalently as field strength in a transmission line or waveguide (passive AUT), the Equation 2.2 becomes as shown in Equation 2.3:

$$\begin{aligned} RL &= 10\ log_{10}\left|\frac{1}{\rho^2}\right|\ \ dB \\ &= -20log_{10}|\rho|\ \ dB \end{aligned} \tag{2.3}$$

where ρ is the complex reflection coefficient at the input of the AUT; that is, the return loss is the negative of the reflection coefficient expressed in dB.

According to Bird (2009), the requirements for the reflection coefficient in a wireless system are often specified at -10 dB return loss bandwidth to verify the accuracy of the simulation and measurement results within the band and emphasize that the weakness of VSWR is unable to verify the accuracy of simulation and measurement results. In this project, return loss is always stated with parameter S_{11}.

2.6.2 Bandwidth

According to Balanis (2012),the bandwidth of an antenna is defined as "the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard.". Bandwidth can be considered as the range of frequencies on either side of the resonance frequency (or center frequency) where antenna characteristics such as input impedance, radiation pattern, radiation efficiency, gain, polarization, beamwidth, beam direction, and side lobe level are within acceptable value at the resonance frequency. The bandwidth for broadband antennas is usually expressed as the ratio of the upper and lower frequencies of acceptable operation. The bandwidth of narrowband antennas is expressed as a percentage of the frequency difference using the Equation 2.4 shown below:

$$\% \, BW = \frac{f_H - f_L}{\sqrt{f_H f_L}} \times 100 \, \% \qquad (2.4)$$

where f_h is the upper frequency that meets with the -10 dB return loss S_{11} value, and f_l is the lower frequency that meets with the -10 dB return loss S_{11} value.

2.6.3 Radiation Pattern

The radiation pattern or antenna pattern is a graphical representation of the radiation properties of an antenna. An antenna's pattern describes how it radiates energy out to space or how it receives energy. The radiation fields from an antenna are inversely proportional with the distance (1/r), whereas the variation with the observation angles (θ, $\emptyset$) depends on the antenna.

Normally, the radiation pattern of an antenna is three-dimensional (3-D). However, the common description of the radiation pattern is presented with two planar patterns called the principle plane patterns. Figure 2.5 shows how the coordinate system is used to describe the principle plane patterns for antenna measurements (Cisco, 2007)

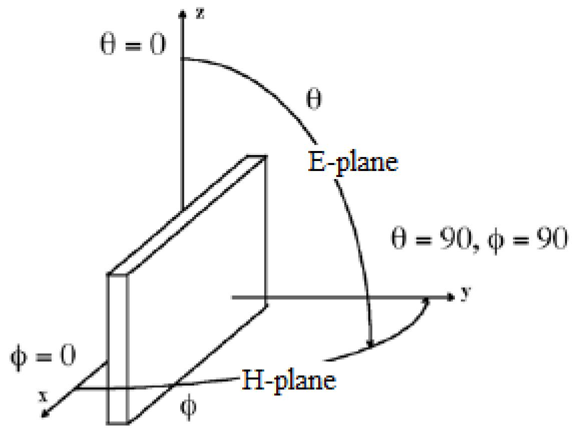


Figure 2.5: Antenna measurement coordinate system (Cisco, 2007)

2.6.4 Directivity and Gain

Directivity, which is equal to its power gain if the antenna is 100 % efficient. It tells how much it concentrates energy in one direction in preference to radiation in other directions. Directivity is defined as the ratio of the radiation intensity in a certain direction to the average radiation intensity. Directivity formula as shown in Equation 2.5:

$$D = \frac{4\pi U_m}{P} \tag{2.5}$$

where *D* is the directivity, U_m is the maximum radiation intensity of the antenna and *P* is the radiated power.

As noted above, directivity is determined exclusively by the radiation pattern of an antenna. When an antenna is used in a system (for example, a transmitting antenna), the focus is on how efficiently it transforms available power at its input terminals into radiated power, together with its directive properties. Gain is used to quantify this. It is defined as 4π times the ratio of the radiation intensity in each direction to the net power accepted by the antenna from the connected transmitter, or in Equation 2.6:

$$G = \frac{4\pi U_m}{P_{in}} \tag{2.6}$$

where G is the gain, U_m is the maximum radiation intensity, and P_{in} is the input power accepted by the antenna.

Based on the directivity equation above, the only difference between maximum gain and directivity is the value of the power used. Directivity may be viewed as the gain of an antenna if all input power appears as radiated power; that is, $P_{in} = P$. Gain reflects the fact that real antennas do not behave in this fashion and that some of the input power is lost on the antenna (Warren L. Stutzman, 2012) .

2.6.5 Antenna Efficiency

The efficiency of an antenna is a ratio of the power delivered to the antenna relative to the power radiated from the antenna. An antenna has high efficiency is most of the power present at the antenna's input radiated away. An antenna has low efficiency when most of the power absorbed as losses within the antenna or reflected away due to impedance mismatch (Balanis, 2012; Pete Bevelacqua, 2012). The formula can be written as the ratio of the radiated power to the input power of the antenna as shown in Equation 2.7:

$$\varepsilon_R = \frac{P}{Pin} \tag{2.7}$$

where ε_R is the radiation efficiency, P is the radiated power and Pin is the input power of accepted by the antenna.

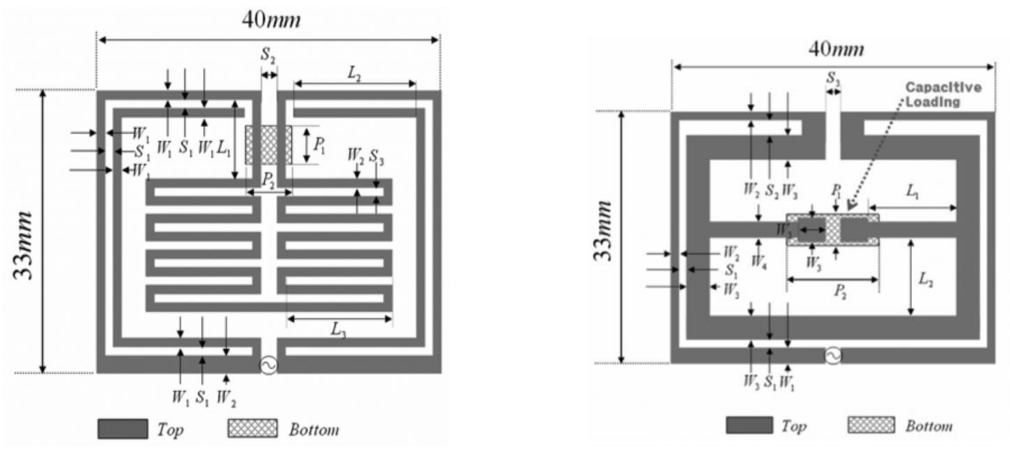
The term total efficiency of an antenna is defined as the radiation efficiency multiplied by the impedance mismatch loss of the antenna when the antenna is connected to a transmission line or receiver (radio or transmitter). This formula can be written in Equation 2.8:

$$\varepsilon_T = M_L * \varepsilon_R \tag{2.8}$$

where ε_T is the antenna's total efficiency, M_L is the antenna's loss due to impedance mismatch, and ε_R is the antenna's radiation efficiency.

2.7 Previous Works

There are few papers proposed the compact size UHF RFID tag antenna. First, the designs of miniaturised structure proposed by Im *et al.* (2009) are folded dipole loop antenna and meander line loop antenna, which have achieved the size reduction of 80 % compared to one wavelength long loop antenna (Im, Kim and Park, 2009). The design of the respective antennas is shown in Figure 2.6.



(a) (b)

Figure 2.6: Antenna design
(a) Meander line loop antenna (b.) Folded dipole loop antenna (Im, Kim and Park, 2009).

The respective directivity (maximum gain) and bandwidth for each antenna configuration are shown in Table 2.2 (Im, Kim and Park, 2009) . The folded dipole loop antenna offers higher directional gain and has larger bandwidth compared to meander line loop antenna. The low radiation efficiency occurs in meander line loop antenna due to ohmic loss (Im, Kim and Park, 2009). Hence, the design of folded dipole loop antenna is adopted for this project due to the advantage of high directivity.

Table 2.2: Simulated and measured result of directivities and bandwidths for each antenna configuration (Im, Kim and Park, 2009).

	Meander line loop antenna		**Folded dipole loop antenna**	
	Simulation	Measure	Simulation	Measure
Directivity (dBi)	-1.7	-2.9	1.2	1.8
Bandwidth (GHz)	0.909 - 0.914 (5 MHz)	0.885 - 0.891 (5 MHz)	0.907 - 0.915 (8 MHz)	0.908 - 0.916 (8 MHz)

In addition, the folded dipole loop antenna has higher far-field gain than meander line antenna as the number of turns of loop of folded dipole loop antenna is lesser compared to meander line antenna (Lai, Xie and Cen, 2013b). This is due to the reason that multiple turns of loop induce mutual coupling effect which reduces the gain efficiency of tag antenna. Therefore, the next compact tag antenna was designed by Lai, Xie and Cen (2013b) has size of 31 mm x 31 m with C-segment parasitic element as illustrated in Figure 2.7. The parameter and the respective value of their antenna design is shown in Table 2.3. The comparison in simulated bandwidth, return loss S_{11} and gain between CST MW software and Lai, Xie and Cen (2013b) is shown in Figure 2.8. Finally, Table 2.4 tabulated the summary between CST MW and Lai, Xie and Cen (2013b) simulation results.

The simulation result has a return loss S_{11} of about -18 dB at 922 MHz, a bandwidth of 11 MHz (915.5 - 929 MHz) and the maximum gain is -4.4 dB at 922 MHz. This model was then simulated again using CST MW with similar design and configuration. The simulated result of CST MW shows that the antenna model has a return loss S_{11} of -19.24 dB at 923.6 MHz, a bandwidth of 19.5 MHz (914.5 - 934 MHz) and a maximum gain of -5.23 dB at 923 MHz. The discrepancy in the simulation results between Lai, Xie and Cen (2013b) and CST MW software is because the unknown characteristic of metal strip at the shorted end and different methods of simulation. For instance, Finite Element Method (FEM) is used in Ansoft HFSS software while time-domain method is used in CST MW software to solve the model.

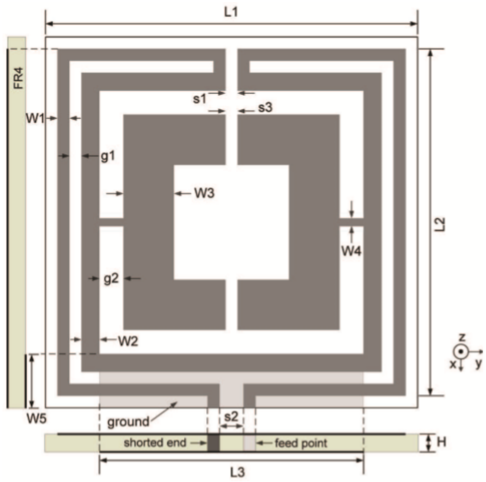
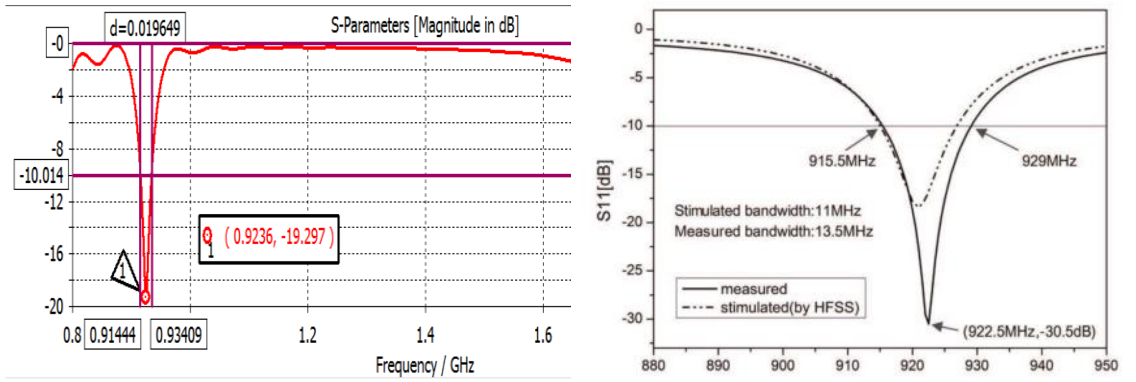


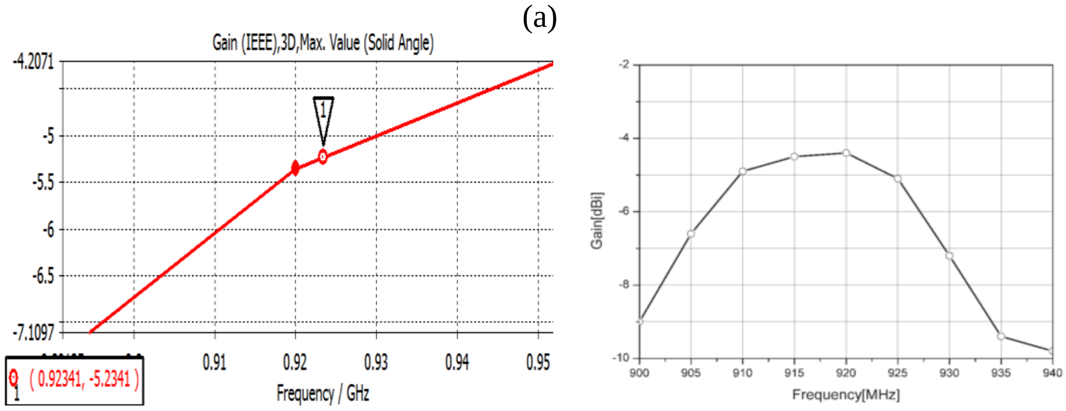
Figure 2.7: Geometry of folded dipole loop antenna with C-segment parasitic element structure (Lai, Xie and Cen, 2013b)

Table 2.3: Parameter and value of the antenna (Lai, Xie and Cen, 2013b).

Parameter		**Values (in mm)**
Antenna Square Edge	L_1	31.0
Folded Dipole Loop	L_2	29.0
	W_1	1.0
	W_2	1.5
	g_1	1.0
	s_1	1.0
	s_2	2.0
C-type Arm	W_3	4.2
	W_4	0.9
	g_2	2.0
	s_3	1.0
Ground	L_3	22.0
	W_5	4.5



(a)



(b)

Figure 2.8: The simulated of CST MW simulation(left) vs Lai, Xie and Cen (2013b) result(right)
(a) Return loss S_{11} and bandwidth (b) Gain

Table 2.4: CST MW software versus Lai, Xie and Cen (2013b) simulated result

Parameters	**CST MW simulated result**	**Lai, Xie and Cen (2013b) simulation result**
Lower Frequency (MHz)	914.5	915.5
Upper Frequency (MHz)	934.0	~926.0
Center Frequency (MHz) (S_{11})	923.6 (-19.27 dB)	~ 921 (~ -18 dB)
Bandwidth (MHz)	19.5	10.5
Gain (dB)	-5.234 at 923.6 MHz	~ -4.4 at 922 MHz

The second design proposed by Lai, Xie and Cen (2013a) is a compact RFID reader antenna with folded dipole loop. It has the same dimension as the first design but it uses split ring resonator (SRR) as parasitic element. This proposed antenna is exclusively designated for USA RFID band, which has larger bandwidth, covered from

902 MHz to 928 MHz. The geometry of the proposed antenna design, and its parameter and value by Lai, Xie and Cen (2013a) are shown in Figure 2.9 and Table 2.5 respectively.

The simulation and measurement results of return loss S_{11} and bandwidth from Lai, Xie and Cen (2013a) are shown in Figure 2.10. The antenna design has return loss S_{11} of -25 dB at 911.5 MHz and the bandwidth of 31 MHz (897 - 928 MHz). It has far-field gain of -2.0 dBi (Lai, Xie and Cen, 2013a).

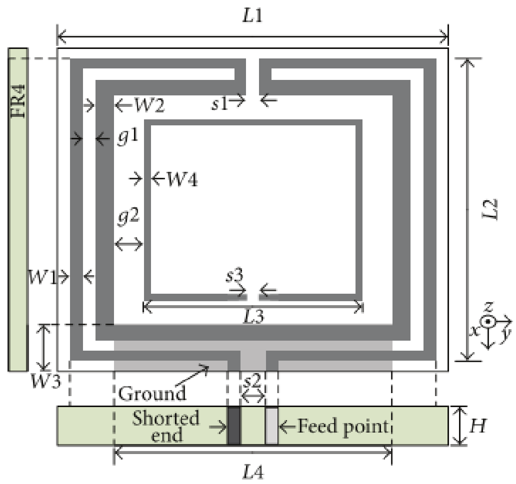


Figure 2.9: Geometry of folded dipole loop antenna with inner SRR parasitic element (Lai, Xie and Cen, 2013a)

Table 2.5: Parameter and value of the antenna (Lai, Xie and Cen, 2013a)

Parameters		**Value (in mm)**
Antenna Square Edge	L_1	31.0
Folded Dipole Loop	L_2	29.0
	W_1	1.0
	W_2	1.5
	g_1	1.0
	s_1	1.0
	s_2	2.0
Inner SRR	W_4	1.2
	g_2	3.3
	s_3	0.9
Ground	L_3	22.0
	W_3	4.5

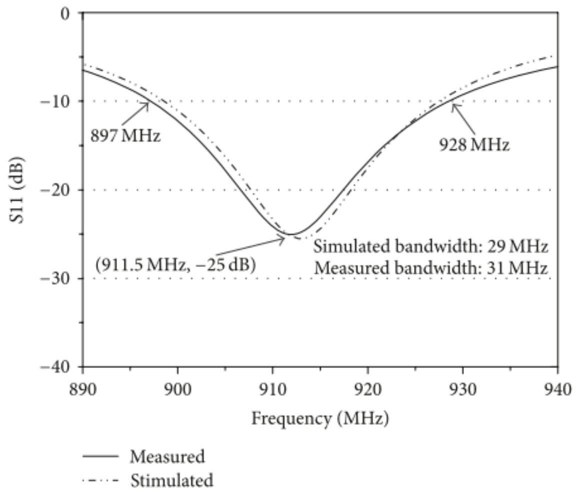


Figure 2.10: Simulated return loss S_{11} and bandwidth of proposed tag antenna (Lai, Xie and Cen, 2013a)

Both designs have common issues. First, the edge of the metal is very close to the substrate edge, which is only 1 mm. According to Balanis (2012), the fringing field around the antenna causes a microstrip antenna to radiate. The fringing effect is greatly reduced when metal edge and substrate edge is too close, causing the poor radiation efficiency. Therefore, it is proposed in this thesis to modify the structure so that the edge of the metal to the substrate edge is kept at a distance at least 2.5 mm. The second problem is that both antenna designs are unable to match over the large frequency range because the frequency deviation of FR-4 substrate is 10 % due to its large tolerance value (Ammann, 1998). For example, the required resonant frequency of Europe UHF RFID band after fabrication using FR-4 substrate is 866.5 MHz, the required simulated resonant frequency to deviate to right by 10 % is 779.85 MHz. Besides that, the antenna design from Lai, Xie and Cen (2013a) does not cover the Europe UHF RFID band. Therefore, Europe UHF RFID band tag antenna design is not applicable in both Lai, Xie and Cen (2013a) and Lai, Xie and Cen (2013b) design after considering the tolerance value. The solutions for these issues are increase the distance between metal edge and substrate edge, and modify the C-segment parasitic element by adding a center slot to it to become E-segment parasitic element. Adding a center slot is to increase capacitive loading effect which decreases the resonance frequency of the tag antenna.

Another compact design from Wang (2015), has displayed the end-fire antenna with meander dipole drivers with dimension of 81× 58 mm^2 using FR-4 as substrate. The geometry of the proposed design and parameters are shown in Figure 2.11 and Table 2.6 respectively. The measured bandwidth is 25 MHz (905–930 MHz) under the condition of VSWR less than 2 or 9.54 dB. The maximum gain of the end-fire antenna is 3.5 dBi. This design has offered very good performance in term of gain among the compact antenna structure design.

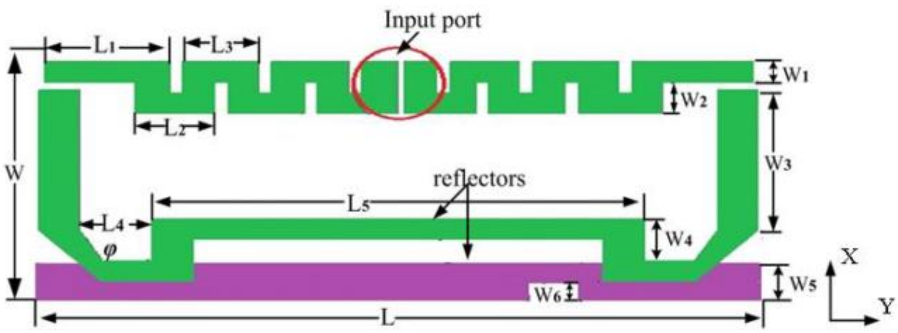


Figure 2.11: Geometry of end-fire antenna with meander dipole drivers (Wang, 2015)

Table 2.6: Parameter and value of the antenna (Wang, 2015)

Parameters	**Value (in mm)**	**Parameters**	**Value (in mm)**
L_1	14.7	W_1	4
L_2	9.2	W_2	6.6
L_3	9.2	W_3	30.6
L_4	8	W_4	9
L_5	54	W_5	8
L	81	W_6	4
φ	120	W	58

However, the antenna design by Wang (2015) is not selected as compact antenna design candidate because it does not fulfil the size of the compact antenna of 40 x 40 mm^2. The size of antenna is changing horizontally all the time as the parameter L_1 is varied to