

**THE DEVELOPMENT OF ANTENNA FOR INDOOR WIRELESS LOCAL
AREA NETWORK APPLICATION**

By

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Submitted to the Department of Electrical & Electronics Engineering

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Electrical & Electronic Engineering
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Approved:

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TRONOH, PERAK

SEPTEMBER 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Wan Salwani Bt Wan Rosli

ABSTRACT

In wireless technology, one of the recently technologies used to have a good performance of antenna is Dielectric Resonator Antenna (DRA). The dielectric resonator antenna (DRA) consists of superior performance features such as it can be fabricated using a high dielectric constant material, covers wide range of frequency band: $f = 0.7-35$ GHz, exhibits high radiation efficiency (95%), excitable through different transmission lines and it can be fabricated in different shapes such as rectangular, cylindrical and hemispherical. The small size of the DRA makes it suitable element for antenna arrays. One of the DRA shapes that have been considered is cylindrical shape. The two elements of CDRA array design which feeding by rectangular aperture coupled slots is computed and analysed by using CST Microwave studio and Agilent network analyser.

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LIST OF ABBREVIATIONS

WLAN	Wireless Local Area Network
DRA	Dielectric Resonator Antenna
CDRA	Cylindrical Dielectric Resonator Antenna
CST	Computer Simulation Technology
dBi	Decibel of an Isotropic
PCB	Printed Circuit Board

CHAPTER 1

INTRODUCTION

1. Introduction

1.1 Background of study

Currently, most of the WLAN technologies operating at frequency 2.4 GHz are widely used in industrial as well as in corporate, public and home environments following IEEE 802.11 b/g/n standards. However, the growing demands from the internet users have changed the world to develop to a better performance in wireless network and standardized around the world such as IEEE 802.11a which operating at 5.6 GHz. Wireless LANs are fast, flexible, cheap and can provide wideband wireless connectivity to multiple electronic user devices which suitable for local area network such as in corporate buildings, public and residential areas. One of the greatest technologies that have been proposed for WLAN application is Dielectric Resonator Antenna (DRA) technology. The conventional of Dielectric Resonator (DR) technologies has been applied as a filter and oscillator applications in early 1960's. Since then, the Dielectric Resonator (DR) continues growing and increasing demands on dielectric resonator technology until it achieved a great technology in communication system.

DRA has various geometries such as cylindrical, spherical, rectangular, disk and hemispherical [6]. In order to have good performances of antenna, the size and the type of DRA geometry that is used in designing antenna must be considered. Most modern world has implemented DRA which can operate at higher frequency bands of the system which 802.11b/g Wireless Local Area Network (WLAN). Many advantages of DRA such as low cost in fabrication, smaller in size, wider in bandwidth [1], high dielectric constant, high quality factor, high radiation efficiency and can radiate at wide range of frequencies [4,6,8]. DRA is suitable used in many communication systems such as tunnels and underground mines application because of its zero conductor losses and suitable for microwave band scale.

To achieve a better performance of DRA, some of the method has been introduced such as linear array antenna. Array antenna is the combination of two or more DRA that involved on the linear planar which gives a smaller and compact in size of

antenna. The antenna gain could be increased because of its small size and lightweight [3,7]. Instead of that, the antenna designers found out several techniques of feeding mechanisms and coupling to DRA that can be applied on Dielectric Resonator Antenna (DRA) designs thus enhance the better performance of antenna in wireless application.

1.2 Problem Statement

Recently, the continuing growth in demand for wireless LANs communications requires a good system for the devices in transferring or sharing the data or information. This kind of higher demands has pushed the industry to develop and improve more with a better technology and system. For conventional patch antenna technology possesses conductor and surface wave losses at millimetre wave frequencies which degrade the antenna performance which is low in bandwidth and the low gain of antenna.

Several factor which can affect the performance of bandwidth in antenna applications. Some of the previous design had been implemented in low dielectric constant. In this case, the effect of low dielectric constant of antenna give a very low radiation in Q-factor and the resonant frequency will be higher. Thus the antenna will be obtained a lower bandwidth and low in gain. Because of that, the efficiency of radiation will become lower and the return loss of antenna design will be more than - 10 dB, which indicate that the antenna absorbs less of fed power. Various techniques have been used to enhance the operational bandwidth in order to achieve the target or desired result.

1.3 Significance of the Project

Today, internet is one of the greatest networks in communication system and it becomes very important for people's needs. The significance of this project is wireless network can be connected to multiple users for local area network such as in the building, for residential areas and etc. By doing this project, it can fulfil the user's demands and gives a better performances in WLAN application.

1.4 Objective

In overall, the project focused more on the process of designing and fabricating a prototype of antenna which considerable in high gain (>5dBi) and bandwidth of the antenna (5.35 GHz to 5.85 GHz) by applying its operating frequency band is 5.6 GHz. Based on the design, the project has been fabricated, tested and measured to obtain for a better performance of DRA in indoor wireless application. The objectives of the project are as the following:

- To study the principle of indoor antenna for WLAN application.
- To design and fabricate a prototype of antenna with highly efficient at 5.6 GHz of operating frequency for IEEE 802.11a WLAN application.
- To test and measure the performance of antenna in wireless application.

1.5 Scope of Study

This project focuses on the designing and fabricating of two elements CDRA's linear array. The operating frequency value that has been applied for CDRA's array is 5.6 GHz as per standard IEEE 802.11a WLAN application. Basically 5.6 GHz of operating frequency produce wideband and more channels which in range of 5.35 GHz to 5.85 GHz and high gain which is about 5 dBi and more. The designing and simulation process was done by using Computer Simulation Technology (CST) Microwave design software and the CDRA's array was being tested and measured by using Agilent network analyzer.

1.6 The relevancy of the Project

Since the WLAN application is one of the important needs to the people in their daily life, so by developing the antenna for indoor in WLAN application is very relevant and important to fulfil the demands of the internet users. On the same time, this project can enhance a better performance of WLAN application and thus it can be commercialized.

1.7 Feasibility of the Project

This project involved in software and hardware design. The methods used to complete the project were designing and simulating the antenna arrays, thus continued with the fabrication of the antenna design. This whole project was completed within the time period given as scheduled in the project Gantt chart as shown in Appendix III.

CHAPTER 2

LITERATURE REVIEW

2. Literature Review

2.1 Dielectric Resonator Antenna

Dielectric Resonator Antenna is the most suitable design that can be able to obtain a great performance in improving wider bandwidth, high gain and also highly efficient when it is being applied at millimetre wave frequency [1-2]. The bandwidth and resonant frequency of Dielectric Resonator Antenna (DRA) depends on the shape, dielectric constant material, radiation mode, dimension of DRA parameter and also excitation method such as aperture-coupling feed, direct-micro strip line feed, coplanar wave guide feed and etc. Some of the advantages of Dielectric Resonator Antenna (DRA) are low cost, small in size, ease of fabrication, high dielectric constant as $10 < \epsilon_r < 100$, high gain and high radiation efficiency due to zero metallic and surface-wave losses [11] that contributes on a great performance of antenna especially in Wireless Local Area Network (WLAN) applications [3].

2.2 Geometry of DRA

These are several of Dielectric Resonator Antenna (DRA) shapes or geometries such as cylindrical, rectangular, hemispherical, disk, spherical and half-split cylindrical [4,6]. Among of those shapes, cylindrical Dielectric Resonator Antenna (CDRA) is most widely used in recently wireless technology because of its more compact size and it is more directional which radiate greater power in one or more directions and thus can improve in wireless application with high gain and great bandwidth [5].

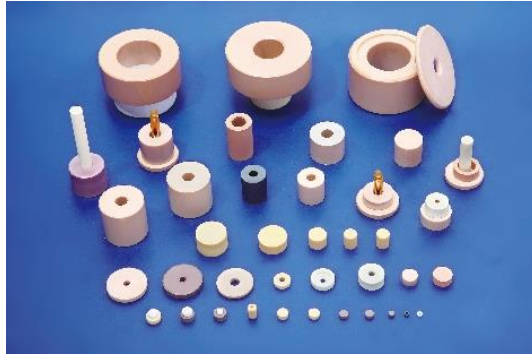


Figure 1 : Types of DRA that normally being used in antenna design

2.3 CDRA's Linear Array

Some applications in communication technology, several DRAs are combined together to form an array since it can improve the gain of antenna design [9]. The combination of antenna will reduce the gap between each of antenna model and thus produce a compact size [14] of prototype antenna. This compact size of antenna can enhance the great efficiency of antenna design. For Cylinder Dielectric Resonance Antenna arrays have three types of array such as two-element broadside array, four-element linear array and four-element planar array. According to the experiment [13], the two-element broadside array can enhance the performance of bandwidth in single DRA compared to other types. However, for the combination of antenna configuration, four-element linear array shows the best element to improve the wideband of bandwidth and gain.

The concept of array antenna, analysis of data and computer simulation of the cylindrical array antenna will be presented according to Ultra wide band impulse (UWBI) signals. Cylindrical array antenna allows for wide angular coverage in azimuth and elevation plane [17]. Several parameters are used to control the antenna design such as the array dimension, the distance between discrete array elements, the side lobe levels, the directivity, the first null beam with and half power beam with [16].

2.4 Feeding Mechanism for DRA Excitation

Many types of feeding mechanisms that can be used in DRA design such as the coaxial probe, a micro strip line coupled to a narrow slot which placed directly on the conducting plane and the feeding mechanism is isolated from the radiating region of signal [19]. Several types of excitation design of DRA which consists of three main shapes: hemispherical, cylindrical and rectangular. Some examples for cylindrical shape are split-cylinder DRA, cylindrical-ring DRA, electric monopole DRA, disk-loaded cylindrical DRA and etc. Each of the excitation shapes of DRA depend on the application that have been used [8]. The type of excitation will eliminate the conduction losses due to the feeding structure. The combination of two coupled resonators can be designed properly to increase the bandwidth and instantaneously to enhance the frequency scanning range [19].

According to the experiment [20] that has been carried out, the bandwidth of the resonant modes can be enhanced by using hybrid structure comparing to the conventional DRA. Most of the DRA design is depending on the value of dielectric constant that is being used to obtain the desired result. By adjusting the effective dielectric, the value of radiation Q-factor can be controlled. Due to the reason of air gap, the effective dielectric constant of the DRA becomes lower in Q-factor but increase in resonant frequency. The bandwidth can be expanded due to the reducing Q-factor and therefore increase in gain.

CHAPTER 3

METHODOLOGY

3. Methodology

This section will discuss the detail explanation of methodology that is used upon completing the project. In this project, there are several steps while completing the project which consists of the study about two elements of CDRA's planar array in WLAN applications, designing and simulating the CDRA's array, fabrication, and lastly testing and measuring the CDRA's array design as referred to the flow chart of the project in Appendix I.

3.1 Study the CDRA's array in WLAN applications

This project work started on preliminary research of the antenna for indoor wireless LAN application. Based on the study part, the author reviewed and studied some of the previous research papers on the technology of CDRA in WLAN applications before proceeding to designing part.

3.2 Design Development of Block Diagram

Several of procedures were considered in order to complete this project work in successfully. From the study, this project focused more on understanding of project background which is about CDRA technologies and how CDRA's planar array was applied in WLAN applications. The collection of data should be based on the type of DRA shape, parameter of antenna design, desired bandwidth and gain that could be achieved, operating frequency of DRA and the feeding mechanisms used in exciting the antenna. By considering these criteria, the next stage has been proceeding with the designing of antenna.

3.2.1 CST Microwave Studio Design

This part describes the design of CDRA's array in CST Microwave Studio (in Fig 2) for 802.11a WLAN applications at 5.6 GHz operating frequency. This software was used to optimize the design parameters of CDRA's array and simulate the design to get the desired results.



Figure 2 : CST Microwave Studio software

By using this CST software, the parameters and the dimension was set up according to the type of antenna shape and the operation type of radiating mode. Designing part in CST Microwave consists of designing ground planar, substrate and also CDRA's array on microstrip line as illustrated in Fig.4.

The first step of designing antenna arrays was designing the substrate planar by using FR-4 material and the epsilon, ϵ that is used 4.9 as shown in Figure 3.

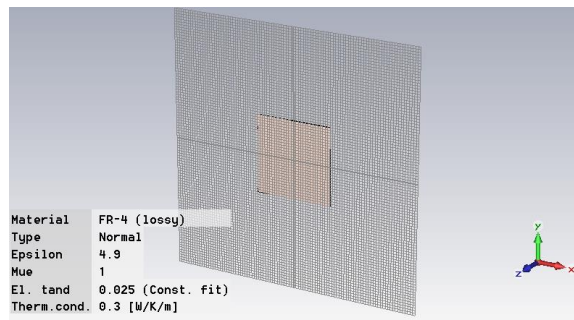


Figure 3 : Substrate plane with FR-4 for CDRA array design

The substrate was designed on the FR-4 planar with 36 x 30 (mm) as same as the parameters for ground plane with copper material.

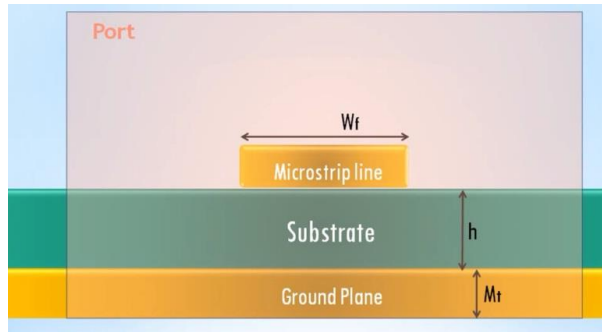


Figure 4 : parameters of substrate, ground plane and micro strip line

Referring to the Fig 6(a), the two element CDRA's planar array was fed by two rectangular aperture coupled slots technique. This was designed on the ground plane of 1.565 mm FR-4 substrate with 4.9 permittivity at front view of planar. These slots were used to excite the radiating elements of two elements of CDRA array. While at the back view of antenna substrate Fig 5(b), the series stub matching of microstrip transmission line was designed so that the power in and power out could be transferred through resonant frequency connector. The 50Ω of microstrip feed line was used to excite the two mutual rectangle slots on the ground plane. The stub length, L of microstrip line as illustrated in Fig 5 can be calculated by using equation 1 and 2.

$$L = \lambda_g / 2 \tag{1}$$

$$L = \lambda_g / 4 \tag{2}$$

where wavelength, λ_g can be calculated by using equation (3).

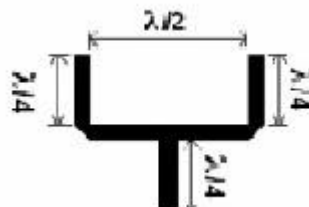


Figure 5 : Stub length of microstrip transmission line

The value of wavelength, λ_g is given as

$$\lambda = \frac{c}{f_r \sqrt{\epsilon_r}} \quad (3)$$

Where :

c : speed of light (3×10^8 m/s)

f : resonance frequency

ϵ_r : permittivity of the dielectric material

The dimension of two elements CDRA in table 1 and the operating frequency was set up to 5.7 GHz for this design and the expected result would be shown.

Table 1 : Dimension of Cylindrical Dielectric Resonator Antenna array design

Height (mm)	Diameter (mm)	Dielectric constant
3	15.5	55

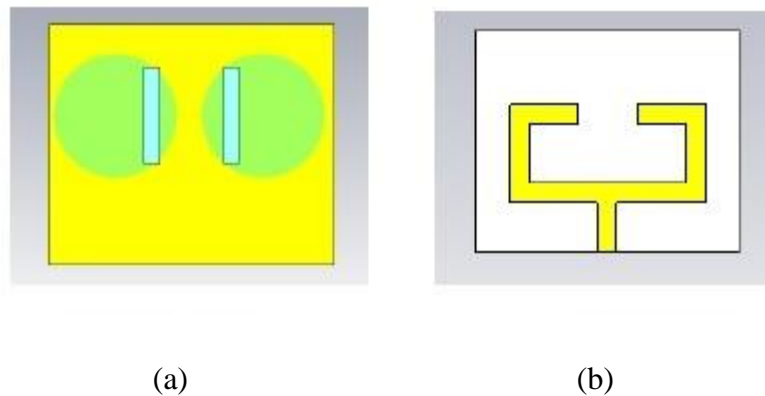


Figure 6 : Two element of CDRA array at the (a) front view and (b) back view

3.2.2 Fabrication process

In fabrication part, the antenna array planar design from the simulation design in CST Microwave Studio software was converted into Printed Circuit Board (PCB) which is FR-4 board by using CST Gerber view. After designing part of array antenna has completed, the CDRA array were fabricated in PCB laboratory based on the design conversion in Gerber. Figure 7 and 8 show the PCB board on the antenna planar design which is in Gerber view. The fabrication of PCB took about two weeks to be completed.

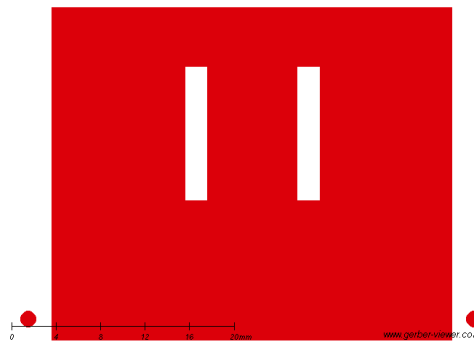


Figure 7 : PCB board at front view of CDRA array design

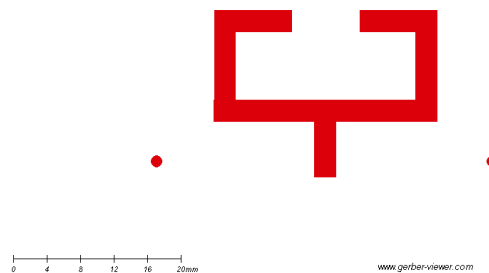


Figure 8 : PCB board at back view of CDRA array design

3.2.3 Testing and Measurement process

The last stage of this project, the design tested and measured by using Agilent Network Analyzer to obtain the desired result. The Agilent Network Analyser used to analyse and determine the range of bandwidth value and the gain that could be achieved by two elements CDRA planar arrays to improve the efficiency of antenna in WLAN application. This process focused more on wider bandwidth range and high gain of far field radiation pattern or Fraunhofer Region of CDRA's array.

The bandwidth range was tested by using Agilent network analyser referring to S11 parameter. The network analyser port was connected to RF connector at CDRA's array as shown in Fig.9 and the result of S11 parameter was being analysed in result and discussion part.

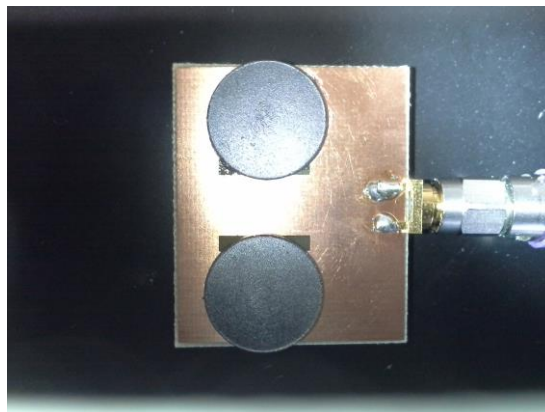


Figure 9 : CDRA's array was connected to Agilent network analyser cable port

To measure the two-dimensional far field patterns, a setup similar to the one shown in Fig 10 is typically used. Firstly, CDRA's planar array or antenna under test (AUT) was mounted at the stable tripod or holder opposite to the reference antenna as illustrated in Fig.10. The reference antenna (transmitter) was connected to port 1 of the network analyser while CDRA's array (receiver) connected to port 2. The separation R between transmit and receive towers has to be great enough for the two antennas to appear in each other's far field. The

distance between two antennas, transmitter and receiver was calculated by using the formula in equation 4.

$$R = 2D^2/\lambda \quad (4)$$

Where D represents the largest antenna dimension, and λ is the wavelength of operation. The frequency range of interest was set up on the network analyser.



Figure 10 : Setup for measure the two-dimensional far field patterns

3.3 Tools and Equipment

To conduct the project work, which the antenna needed to be fabricated, thus the test and measurement of the antenna performance can be conducted. The consumable tools and equipment that involved in this project are categorized by these three components which involved in designing, fabrication, and testing and measurement process.

3.3.1 Designing the Antenna

To design the antenna, first step is to determine the antenna geometry. Based on preliminary research, the geometry of the antenna has been selected and the parameters of the design can be set up by using Computer Simulation Technology (CST) microwave software.

CST Microwave Design – CST Microwave Design is being used to carry on the simulation of Dielectric Resonator Antenna (DRA) design. This software also enables to simulate and analyse the result of antenna design accurately which is for high frequency devices.



Figure 11 : CST Microwave Studio software logo

3.3.2 Fabrication of Antenna

After the antenna has been designed with appropriate parameters, the antenna will be fabricated at Fabrication Laboratory. To conduct this fabrication process, all the antenna tools and equipment would be prepared in Fabrication Lab.

Cylindrical Dielectric Resonance Antenna (CDRA) – This is the main components of the antenna which function as to radiate the signal of communication. The parameters and dimension of this

CDRA will be set up to simulate in the software design. Figure 12 shows the CDRA size is very small compared to 50 cent size.

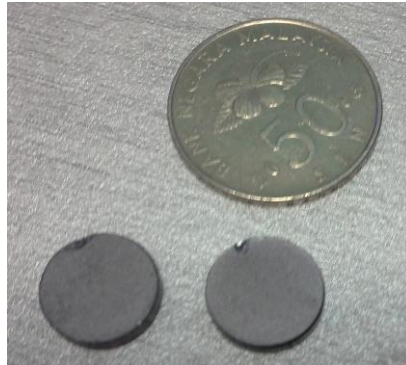


Figure 12 : Comparison between CDRA and 50 cent sizes

FR-4 board – The prototype of antenna design that is CDRA was implemented to this type of board which function as a planar substrate.

3.3.3 Testing and Measurement of Antenna

This is the last process of the project that is very important to indicate that the antenna is in good performance in terms of bandwidth, gain, and efficiency of the system. The data was collected and analysed based on the results of testing and measuring of antenna design. To apply this process, the CDRA array was tested and measured by using Agilent network analyzer.

Agilent Network Analyzer – This equipment used to measure the S11 and S21 parameters of bandwidth range and also the gain far field radiation pattern of antenna.



Figure 13 : Agilent Network Analyser for S21 parameter

3.3.4 Final Year Project schedule and Submission dateline

The Final Year Project I and II flow chart schedules and submission date are depicted in Appendix II and Appendix III respectively.

3.3.5 Project Activities and Milestone

The project activities and milestone during Final Year Project I and II are depicted in Appendix IV and Appendix VI respectively.

4. Result and Discussion

4.1 Design CDRA's Linear Array in Fabrication on PCB

Based on the Figure 14, it shows the design at front view on (a) gerber view which converted from the design in CST Microwave Studio and also on PCB board view after the antenna planar fabricated completely. These two rectangle aperture coupled slots technique were excited through 50 Ω microstrip feed line which made up of copper materials. The two same sizes of CDRA arrays were feed on these two slots.

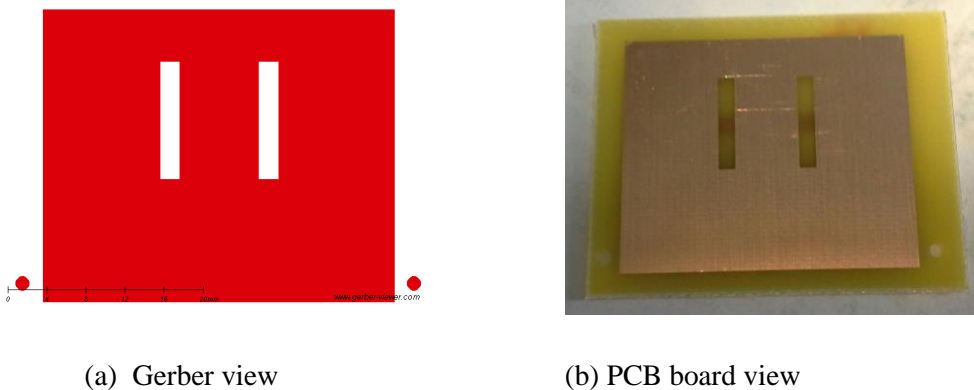


Figure 14 : Front view of antenna array planar in Gerber and PCB board

As in Figure 15 illustrated, it shows the antenna planar design at back side view on (a) gerber view and (b) PCB board view. The series stub match of microstrip line as explained in the CST Microwave studio designing part which from copper material functions as a transmission of power from the RF connector to the CDRA's array. The power transferred from the microstrip line to the CDRA arrays by electromagnetic coupling.

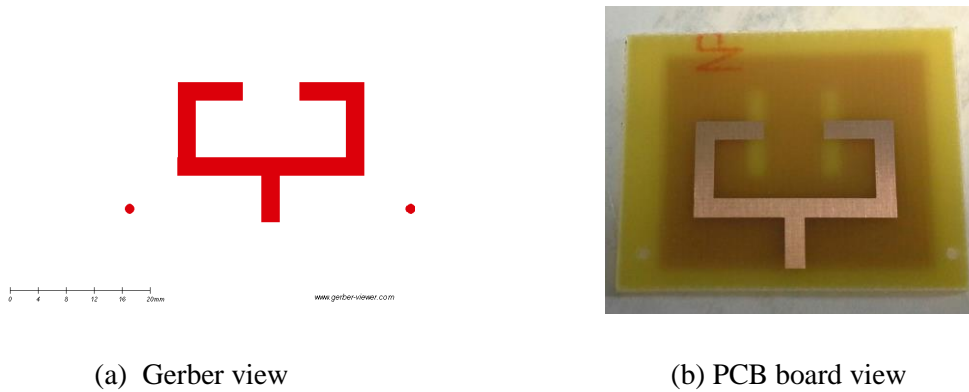


Figure 15 : Back view of antenna array planar in gerber and PCB

Figure 16 shows the design of CDRA's array were fabricated completely and it could be seen by comparing with the 50 cent shape, the CDRA's array is smaller and more compact in size which compatible for being commercialized to the communication industries.

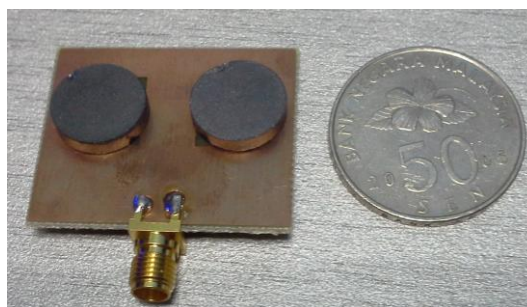


Figure 16 : Comparison of the size between CDRA and 50 cent

4.2 CST Simulation and Measured result

Scattering parameters or S-parameters describe the electrical behaviour of linear electrical networks when undergoing various steady state stimuli by electrical signals. S11 parameter graph and radiation pattern were very important to determine and analyze the range of bandwidth value and the gain value for CDRA's array. The parameters of dual-elements CDRA's array with two rectangle aperture coupled slots was set up according the size of antenna that available in the market. These parameters value of CDRA's array design could be referred in Table 1.

4.2.1 Return Loss

According to the S11 parameters simulated in CST Microwave studio and measured result, it shows that the range of bandwidth that could be achieved for CDRA's array design at 5.7 GHz operating frequency are 5.2 GHz to 5.8 GHz and 5.56 GHz to 5.93 GHz. The return loss of simulated and fabricated for both resonance frequencies are below the -10 dB as stated in Fig 17 and Fig 18.

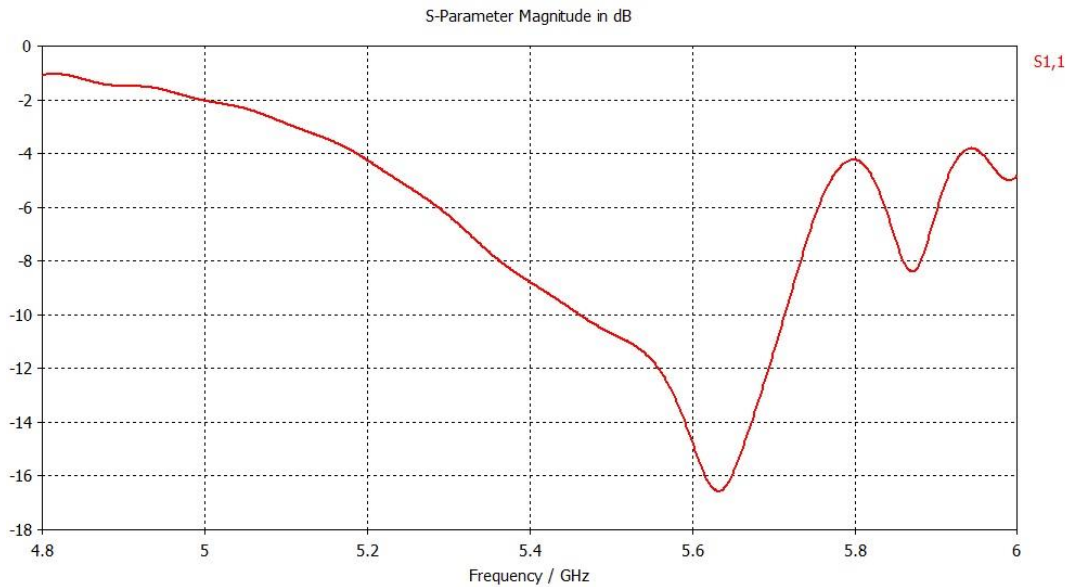


Figure 17 : Return loss (dB) in S11 parameter simulated

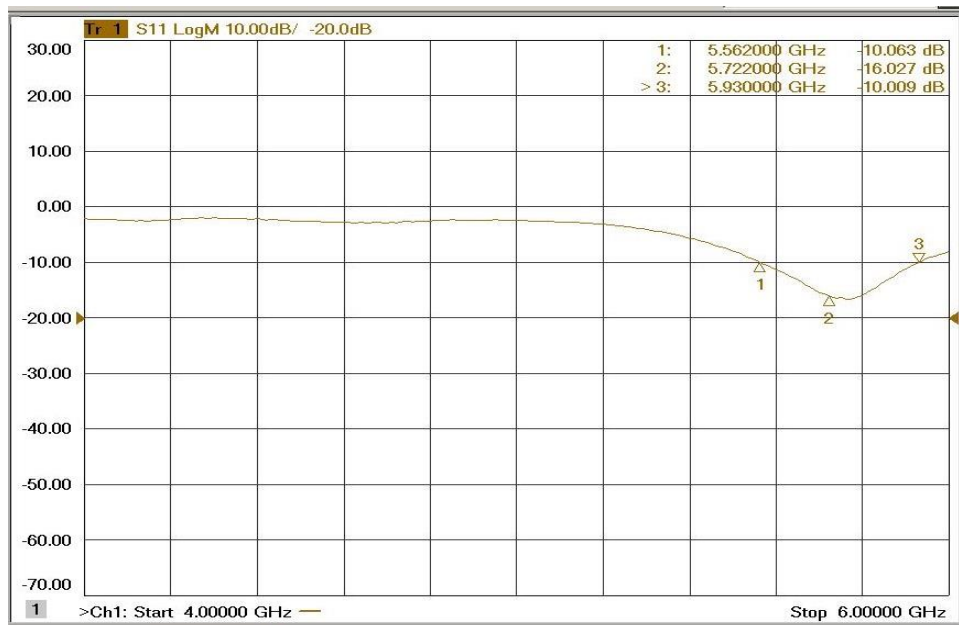


Figure 18 : S11 Return loss (dB) in S11 parameter measured

The return loss in S11 parameter would be determined the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line. The range of bandwidth CDRA's array in the simulated was enhanced from 5.2 GHz to 5.85 GHz because of the series stub matching of microstrip feed network has been applied in the CDRA's planar array design. This microstrip feed transmission line is one of the mechanism that can excite the antenna and enhance the range of bandwidth for wireless application.

4.3.2 Far field radiation pattern in CST simulation and S-21 Parameters Network Analyzer test

Based on the simulated and measured result as illustrated in Fig 19 and Fig 20, the far-field radiation pattern of two elements CDRA's array determine the value of antenna gain about 9.5 dBi and 5.171 dBi at 5.7 GHz operating frequency. The direction of radiation signal focused more to the main lobe compared other lobes.

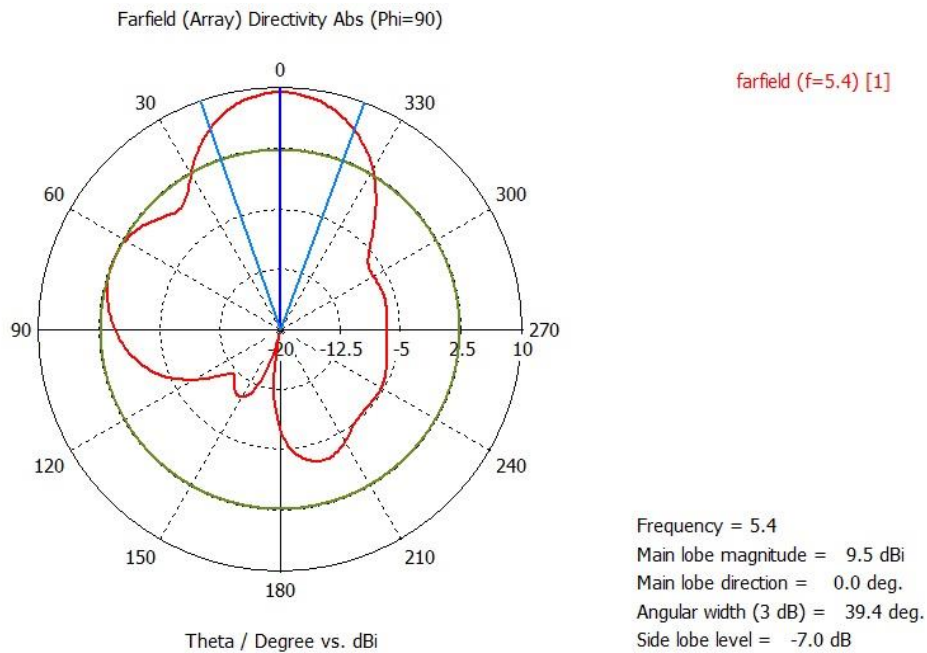


Figure 19 : Far field radiation pattern in simulated result



Figure 20 : Far field radiation pattern in measured result

A radiation pattern is the combination of the electric and magnetic field strengths of an electromagnetic wave vary inversely as the distance from the antenna or source and other contributions to the field strength. The far field region is the most important, as this determines the antenna's radiation pattern. Also, antennas are used to communicate wirelessly from long distances, so this is the region of operation for most antennas.

Basically, the radiation pattern of two elements CDRA arrays is near omni-directional, thus it is extremely suitable for applications in Wireless Local Area Network communication. Because of the WLAN Access Points (APs) are normally placed at higher building thus they need for a more directional of radiation pattern.

The differences in the simulated and measured results are due to the fabrication of DRA element, presence of air gaps, different placement of elements and cable transmission loss factors. The machining of DRA elements are very small sizes since the ceramics of DRA have a tendency to chip and fracture easily. Thus, it could be quite challenging to get the exactly in simulated results. The presence of unwanted air gaps between the CDRA and the two mutual rectangle aperture slots feed is not perfectly flat so that it could lead to significant changes in input impedance or resonant frequency. Besides that, the different placement of two elements of CDRA linear array in simulation and fabrication design and also the transmission loss in microstrip line could lead to the changes of the results.

5. Conclusion and Recommendation

5.1 Conclusion

In overall, the project was successful until the process of designing and fabricating a prototype of antenna which considerable in bandwidth of the antenna (5.56 GHz to 5.93 GHz) with the gain is 5.17 dBi by applying its operating frequency band is 5.6 GHz. Based on the design, the project has been fabricated, tested and measured to obtain for a better performance of DRA in indoor WLAN application. The desired frequency of interest at 5.6 GHz can be enhance the efficiency of antenna and suitable for indoor 802.11 a WLAN application.

5.2 Recommendation

In this project, the testing and measurement has been done by radiating the signal of reference antenna (transmitter) to the CDRA array as a receiver without using any type of reflector. This project can be enhanced the performance of antenna by using reflector such as parabolic reflector antenna. Since the main advantage of a parabolic antenna is that it has high directivity so it could increase the gain of antenna and thus improve the CDRA's array performance.

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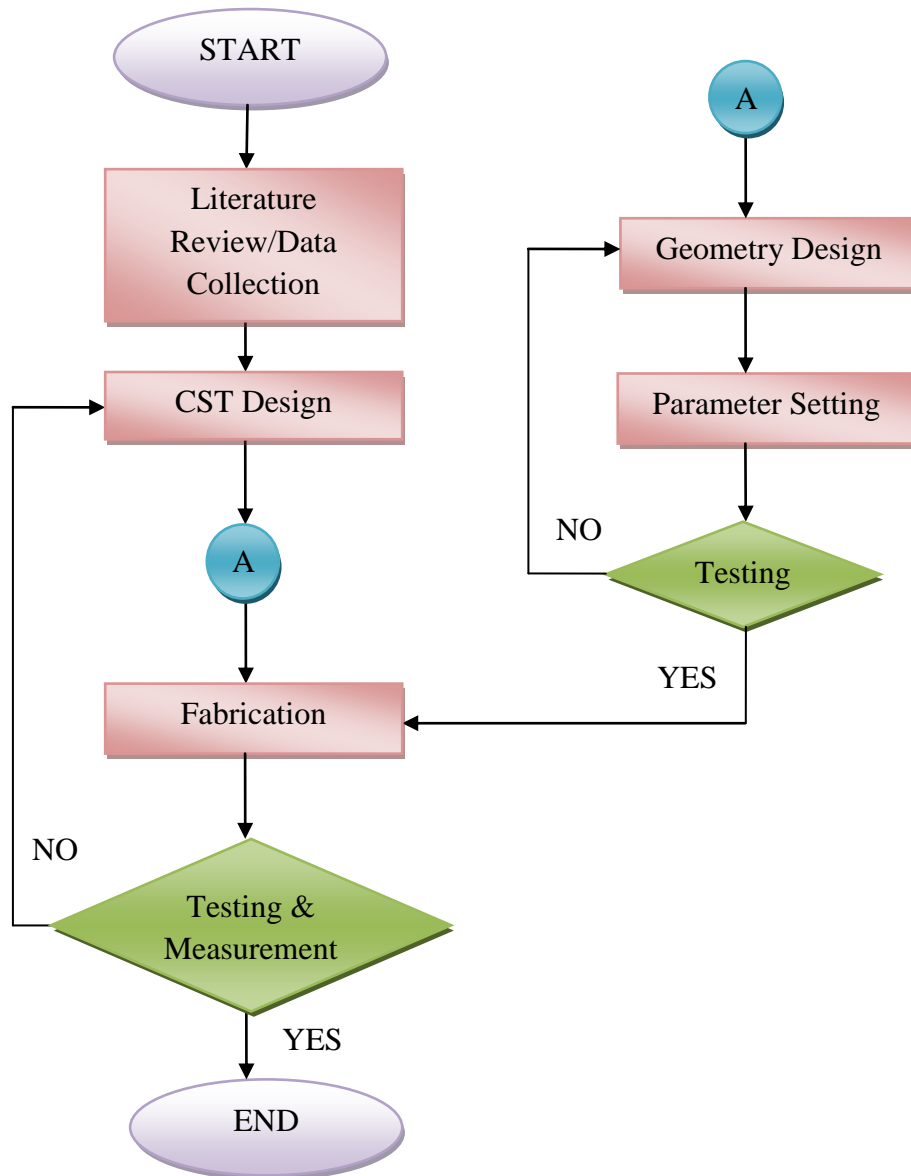
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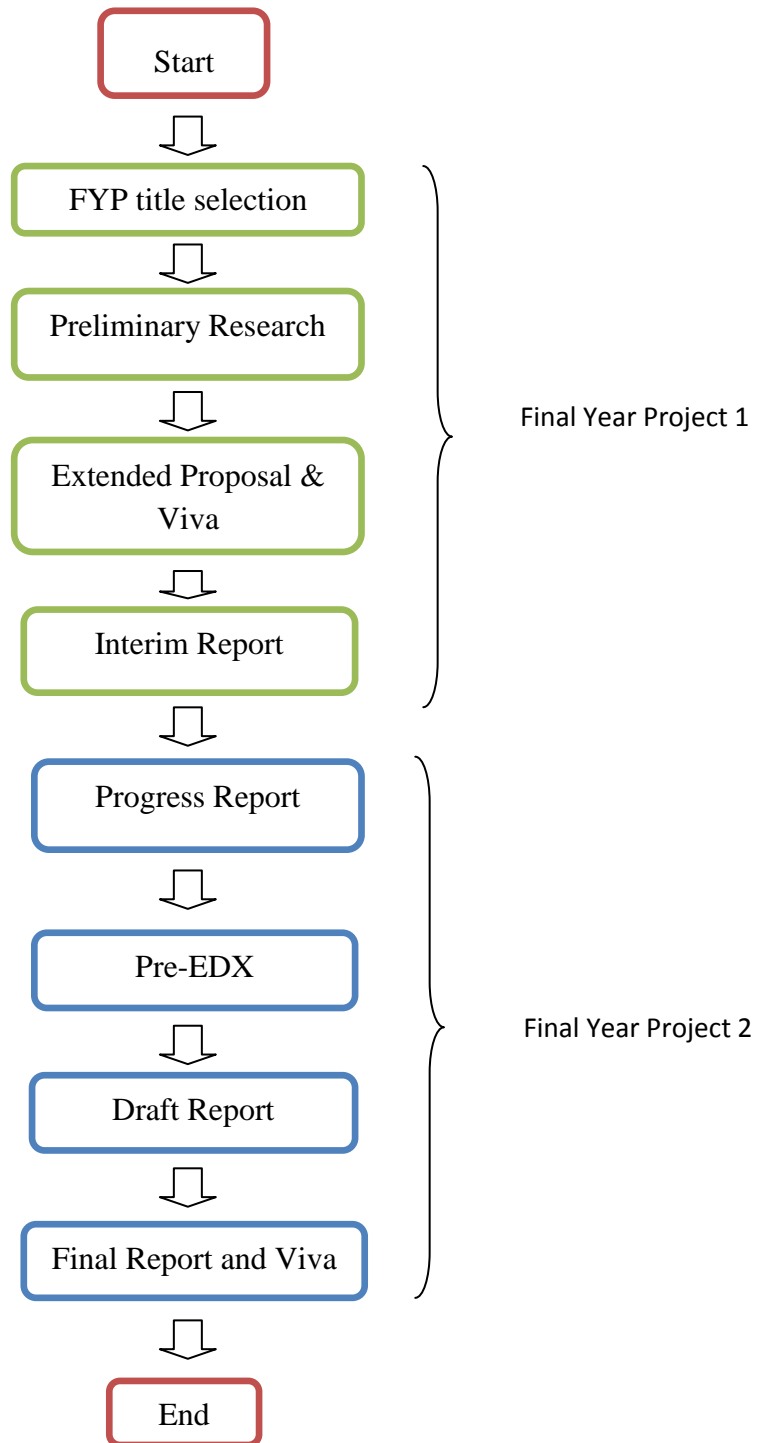
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7. APPENDICES

APPENDIX I



APPENDIX II



Appendix III

Project Activities	Week																											
	FYP 1														FYP 2													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28
Submission of FYP title selection	◆																											
Submission of Extended Proposal						◆																						
Proposal Defence								◆																				
Submission of Interim Report													◆															
Submission of Progress Report																						◆						
Pre-EDX																										◆		
Submission of Draft Report																											◆	
Submission of Final Report and Viva																												◆

Appendix IV

Project Activities	Week																												
	FYP 1														FYP 2														
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	
Preliminary research	■	■	■	■	■	■	■	■	■																				
Design antenna by using CST software										■	■	■	■	■	■														
Fabrication of antenna by using FR-4 board															■	■	■	■	■										
Testing and measure the antenna by using Agilent network analyser																			■	■	■	■	■						
Analyse data																						■	■						
Documentation																										■	■	■	■

Appendix VI

Project Activities	Week																											
	FYP 1														FYP 2													
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28
Completion of preliminary research							◆																					
Completion of designing antenna by using CST software													◆															
Completion of fabricating antenna																	◆											
Completion of testing and measure the antenna by using Agilent network analyser																					◆							
Completion of analysing data																							◆					
Documentation																											◆	

