Analysis of 2 by 2 Rectangular Microstrip Patch Array Antenna at 2.4 GHz Frequency For Wireless Local Area Network Application.

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Abstract—**Antenna is the primary part of communication system. Rapid developments in wireless local area(WLAN) network also parallel with advancements in compactness and efficiency of antennas. This paper discusses on the analysis of 2 × 2 Rectangular Microstrip Patch Array Antenna. The study concentrates on frequency of 2.4 GHz for WLAN application. The objectives of this project are to design and analyze both simulation and measurement results for the proposed antenna to make comparison. The design is fabricated on FR4 substrate of dielectric constant, ε_r equal to 4.9 and thickness of 1.6mm respectively. A combination of several equations and technique are used to get the initial geometrical parameters. The antenna can operate at 2.4 GHz within the desired specification by adjusting the dimensions. A combination of several equations and technique are used to get the initial geometrical parameters. The antenna has return loss of -14.672 at 2.4 GHz for simulation and -21.657 at 2.58 GHz for measurement. The antenna has an directional characteristic. The design and simulation are done using Computer Simulation Technology CST Microwave Studio software and the measurement using Vector Network Analyzer (VNA). The design procedure, simulated and measured has been discussed in this paper.**

Keywords— **array antenna, CST Microwave Studio, microstrip, simulation, substrate FR-4, Vector Network Analyzer.**

1.0 INTRODUCTION

Imagine the world without antenna, there will be no efficient wireless local area network (WLAN) between two entities. It is the WLAN communication, which effectively brings the whole world together. In the recent years, the development in communication systems requires the advance of microstrip patch antenna that are capable of maintaining high quality performance over a wide spectrum of frequencies [1]. One of the greatest humankind's natural resources is the electromagnetic spectrum and the antenna has been influential in harnessing this resource.

A. Microstrip Patch Antenna

Microstrip technology was the desired invention for its advantages. The technology itself has found extensive application in wireless local area network system owing to their benefits such as low-profile, conformability, low-cost fabrication and ease of integration with feed networks [2]. They are the original type of microstrip antenna which described by Howell as the two metal sheets together form a resonant piece of microstrip transmission line with a length of approximately one-half wavelength of the radio waves [3].The design of microstrip antenna basically depends on the size and the shape of the patch, and the relative permittivity of the substrate.

B. Wireless Local Area Network Communication

Wireless technology is rapidly evolving and ever-larger numbers of people are relying on the technology directly or indirectly. Wireless is a well known term used to describe telecommunications in which electromagnetic waves carry the signal over the communication path rather than some form of normal wire. The first wireless transmitters went on the air in the early 20th century using radiotelegraphy which is Morse code [4]. A wireless network offers advantages of mobility and elimination of unsightly cables. However, wireless communication experiencing more interference as compared to standard wired communication. It is also include the potential of radio interference due to weather, other wireless devices, or obstructions like walls [5].

C. Antenna Array

The phased array is a key component in the current and future WLAN application. Series array configuration offers unique advantages to the microstrip antenna designers [6]. First, feed line lengths are greatly reduced, and thus reducing the radiation and dissipation losses which decrease array efficiency. Further, antenna arrays are used in order to achieve higher gain. Better gain will be produced if the number of antenna is increased. An antenna array is more demanding for electromagnetic simulation than single element antennas due to their electrical size.

2.0 METHODOLOGY

Fig. 2 shows the flowchart for the proposed project. The procedure of analyzing and designing a 2 by 2 rectangular microstrip patch antenna is explained below. A rectangular microstrip patch antenna array is designed for wireless communication. Finally, the results obtained from the simulations are demonstrated.

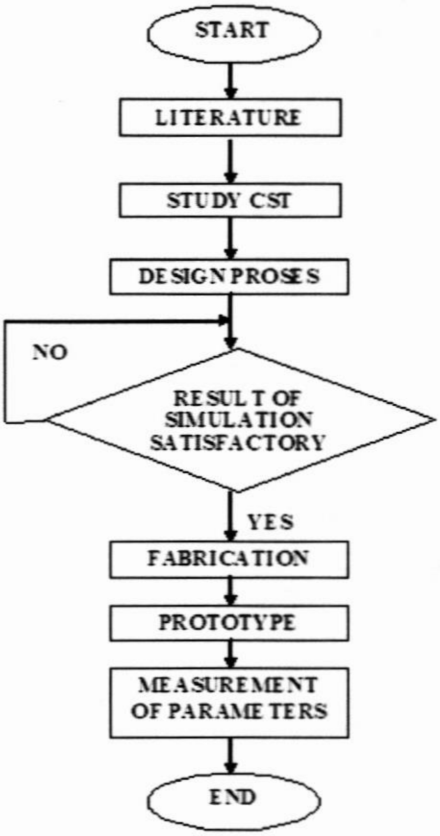

Fig 1: Design flow diagram for the proposed patch antenna.

A. Design Specification

The three essential parameters for the design of a rectangular microstrip patch antenna specifications are:

i) Frequency of operation (*fo*): The resonant frequency of the antenna must be selected properly. Table I shows the frequency range that are most commonly used for wireless communications. The two bands, Super High Frequency (SHF) and Extremely High Frequency (EHF) bands are presently being used for wireless services. The resonant frequency, *fo* selected for the design is 2.4 GHz.

TABLE I
FREQUENCY BANDS FOR WIRELESS COMMUNICATION

Frequency Range	***Types***
High Frequency (HF) : 2-30 MHz	Prime band
Very High Frequency (VHF) : 20-300 MHz	Prime band
Ultra High Frequency (UHF) : 200-3000 MHz	Prime band
Super High Frequency (SHF) : 2-30 GHz (also known as microwave)	Increasing use
Extremely High Frequency (EHF) : 20-300GHz (also known as millimeter wave)	Increasing use

ii) Dielectric constant of the substrate ($\mathcal{E}r$): For a good antenna performance, a thick dielectric substrate with low dielectric constant is desirable for better efficiency, larger bandwidth and better radiation [7]. However, such a configuration leads to a larger antenna size. In order to design a patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth [8]. Hence, a trade-off must be realized between antenna dimensions and antenna performance [9].

iii) Height of dielectric substrate (h): For the rectangular microstrip patch antenna to be used in WLAN system, it is necessary that the antenna is not bulky. The height of the dielectric substrate is selected as 1.6 mm.

Hence, the essential parameters for the design are:

TABLE II
DESIGN SPECIFICATION

Specification	*Value*
Frequency, *fo*	2.4Ghz
Substrate Material	FR-4 (loss free)
Dielectric constant, $\mathcal{E}r$	4.9
Substrate Thickness, h	1.6mm
Copper Thickness	0.035mm

B. Design Procedure (Theoretical Analysis)

The designed antenna is a 2 by 2 array. The first step in the design is to specify the dimensions of a single microstrip patch antenna. There are several equations that need to be considered in order to configure the length and width of the patch antenna. Fig. 3 shows the basic configuration of the patch antenna.

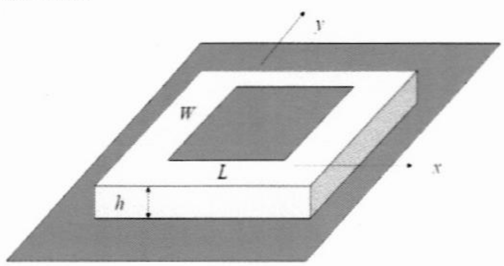

Fig 2: Basic Configuration of Microstrip Patch Antenna

The width of patch element, W is given by (1):

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

where,
c is the speed of light, given as $c = 3\times10^8$ m/s

Equation (2) shows the length of patch element, L:

$$L = [c / (2fo\,(\varepsilon_e)^{-1/2})] - 2\Delta L \tag{2}$$

Where,

ε_{reff} is effective relative permittivity, given by (3):

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{\frac{1}{2}} \tag{3}$$

and ΔL , the fringe factor given by (4):

$$\Delta L = 0.412\,h\left[\frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.3)\left(\frac{w}{h} + 0.8\right)}\right] \tag{4}$$

All parameters are calculated and accordingly. Table III illustrates the parameters used in designing the microstrip patch antenna.

TABLE III
PROPOSED PATCH ANTENNA DESIGN PARAMETER

Parameter	Value (mm)
Patch width, W	36.38
Patch length, L	27.5
Substrate width, Wg	120
Substrate length, Lg	90

C. *Quarter-Wavelength Transformer*

Since the design is 2 by 2 microstrip array antenna, the application of feed network is vital in order to connect all the patches. The simplest way to get the width and length of the feeder according to its respective impedance is by using the online tool called Microstrip Line Calculator [10].

It is important to match two values of impedance that it can be connected together by a $\lambda/4$ transmission line having characteristic impedance equal to the square root of their product. A λ /4 often referred as quarter-wave transformer. It is frequently used in antenna work as desired, which is to transform the impedance of an antenna to a new value that will match a given transmission line. For the width and length of the quarter wave transformer and 50Ω feedline are obtained by the Txline Calculator in MWO software. The obtained values for width and length of 50 Ω and quarter-wave transformer feed line are shown in the Table IV.

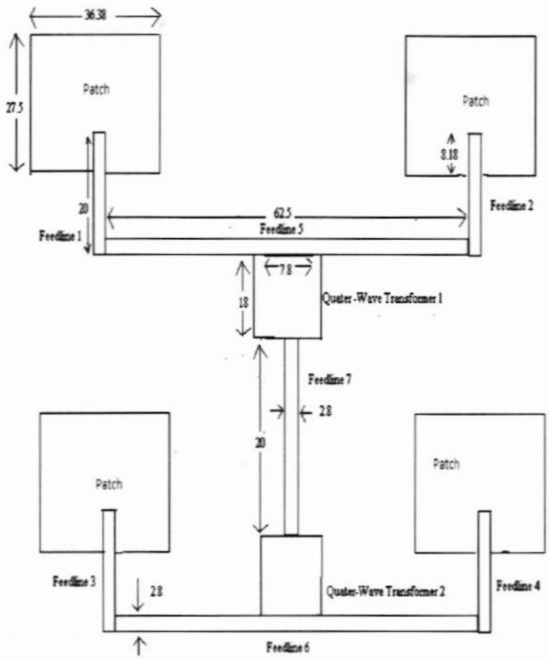

Fig3. Front view of the 2 by 2 Rectangular Microstrip Patch Array Antenna

TABLE IV
FEEDER DIMENSION

Impedance	Width (mm)	Length (mm)
50 Ohm Transmission feedline 1,2,3 4 and 7	2.8	20
25 Ohm Quarter-Wave Transformer 1 and 2	7.8	18
50 Ohm Transmission feedline 5 and 6	62.5	2.8

D. *Probe Feeding*

The probe feed (coaxial feed) is a common technique used for feeding microstrip patch antennas. To get the exactly location of the feed point a trial and error method is used. The main advantage of this type of feeding scheme is that the feed is very simple and easy to obtain input match with its input impedance. This feed method is easy to fabricate and has low radiation.

3.0 RESULTS AND DISCUSSION

In this topic, simulation outcome is explained. Fig. 5 shows the final layout design of 2 by 2 rectangular microstrip patch array antenna. To differentiate the main effect of single and array antenna, the analysis of both methods are compared as shown in Table V. Both antennas were simulated by using 2.4Ghz frequency.

A. Line Impedance, Gain, Directivity and Efficiency

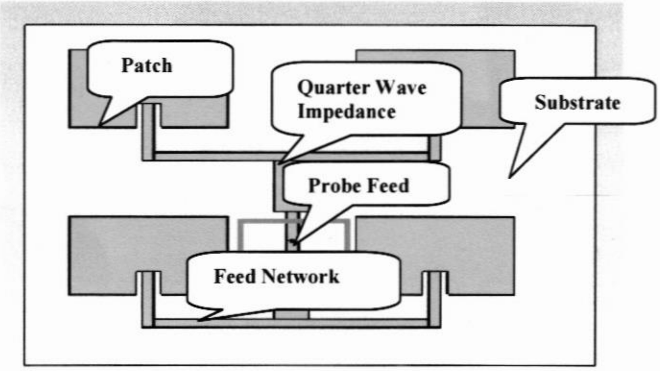

Fig 4: 2x2 Microstrip Patch Array Antenna Front Layout

TABLE V
SIMULATION RESULT'S PARAMETERS OF 2 by 2 ARRAY ANTENNAS

Parameter	*2 by 2 microstrip patch antenna*
Gain	10.53 dB
Directivity	10.71 dBi
Line Impedance	49.9937 Ω

The line impedance for the antenna is which 49.9937 Ω since it using the probe feed (coaxial feed) techniques. From Fig. 6, it shows that the gain for array antenna (10.53 dB) and the directivity is 10.71.

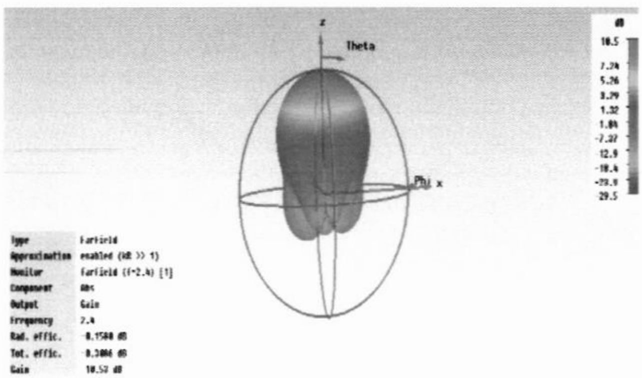

Fig 5: Radiation Pattern Microstrip Patch Array Antenna (3D view)

The radiation efficiency of array antennas is 98.3%. It can be concluded that the array antenna generates more intensity or focusing at the center of the radiation. Gain gets higher as the directivity gets higher. This comparison meets the theory that array antenna design is primarily used to increase the gain and directivity of the antenna itself.

B. Radiation Pattern

The radiation pattern for simulation and measurement plot can be seen below. For simulation, the angular width (3 dB) obtain is 61.0 degree while the side lobe level is -22.3 dB. The front-to-back ratio obtain is 20.3 dB.

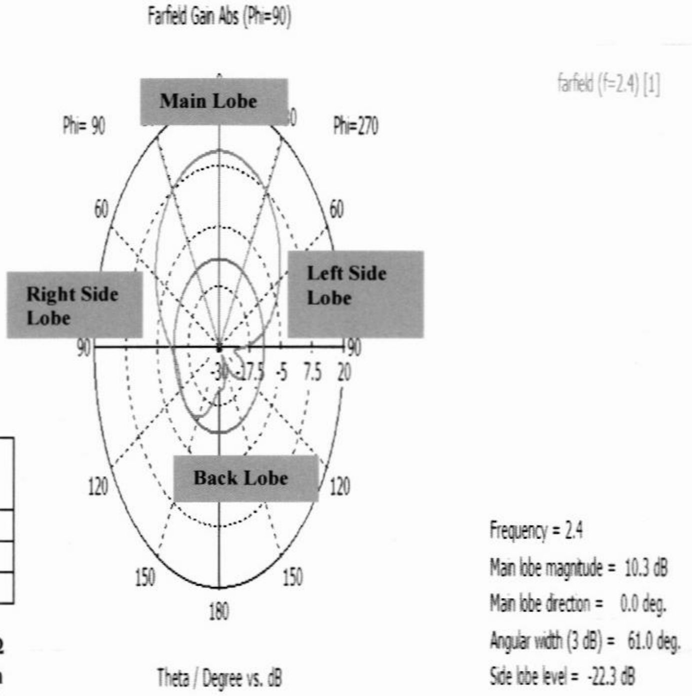

Fig 6: Radiation Pattern of 2 by 2 Rectangular Microstrip Patch Array Antenna (Simulation Polar view)

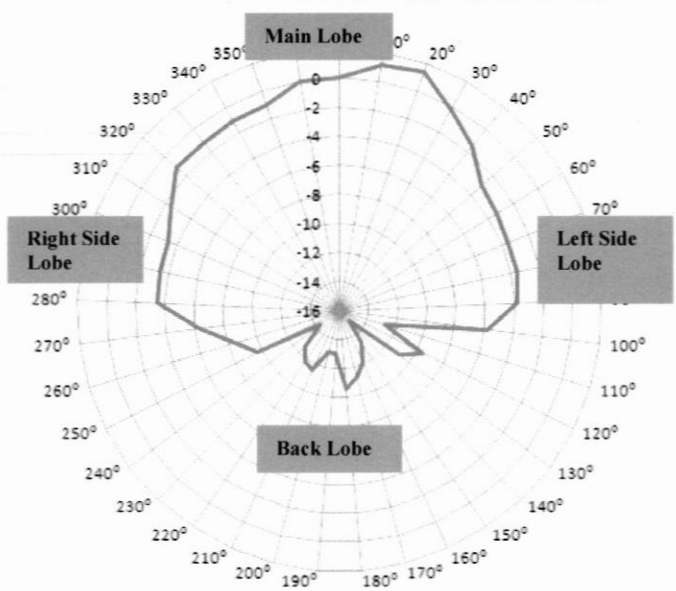

Fig 7: Radiation Pattern of 2 by 2 Rectangular Microstrip Patch Array Antenna (Measurement Polar view)

To achieve desired output, optimization process is performed manually by altering the width and length of the patch using CST. Table VI shows several different measurements and the effect on S_{11}, VSWR, and gain and directivity value. The good measurement is highlighted in blue colour.

TABLE VI
VARIOUS DIMENSION EFFECT ON S11 RESPONSES

Parameter Varied (Patch)		*S_{11} (dB)*	*VSWR*	*Gain (dB)*	*Directivity (dBi)*
Width (mm)	*Length (mm)*				
38.78	**27.5**	**-5.7163**	**24.3662**	**10.53**	**8.93**
37.38	**27.5**	**-8.7587**	**2.6990**	**10.68**	**10.15**
36.38	**27.5**	**-14.672**	**1.616357**	**10.53**	**10.71**

C. *Return Loss*

S-parameters (S_{11}) which is also known as return loss is reflected from the transmitter to an antenna. For good result, the value should be lower than -10dB [9]. Fig. 10 shows values of S_{11} taken from optimization and measurement result that falls on 2.4 GHz and 2.58GHz frequency. The best optimization S_{11} outcome for microstrip antenna array design is -14.672 dB and measurement S_{11} obtained is -21.657dB. The measured operating frequency has shifted about 7.5% from the simulated operating frequency.From the graph, it is slightly shifted to the right. The discrepancy between the measured and simulated results stems from the fact that in the environment for the place that the measurement takes is one of the main factors effects the frequency shifted. Suppose the around the environment should be in vacuum so the better results because human, another equipment, win, and another environment fact can effect for the measurement results. Another reason for the discrepancy can be the gap width of the waveguide line at the antenna center. The return loss is sensitive to small variations of the gap.

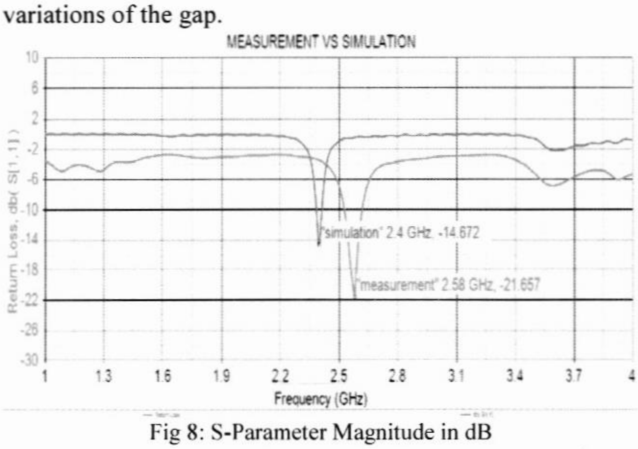

Fig 8: S-Parameter Magnitude in dB

D. *Voltage Standing Wave Ratio (VSWR)*

VSWR is a measure of how matched an antenna is to the cable (line) impedance. This means that all the power is transmitted to the antenna and there is no reflection [11]. A perfectly matched antenna would have a VSWR of 1:1. This indicates how much power is reflected back or transferred into the cable. Fig. 11 shows the VSWR is equal to 1.453 at the 2.4GHz frequency for simulation and the VSWR is equal to 1.18 at the 2.58GHz frequency for measurement.

The measured result is also slightly shifted to the right. The discrepancies between measurement and simulations are caused by the assumption of the finite substrate and measurement setup. A small amount of asymmetry in the antenna structure, the feed, and the nearby objects such as the cable feeding the antenna can cause noticeable errors on the VSWR results.

The equipment used for measurement also can effect the VSWR results. The equipment purpose should be in a good condition. All procedures for using the equipment must be followed and supervised by a person who expert in using the equipment or experience technician. The calibration must be done before started to use the equipment.The others reasons for the discrepancy between measurement and simulation is caused by the fabrication process. The printer used to print the design layout from the CST simulation must have high resolution and high quality printout. The fabrication process needs to be handled with care so that the design layouts are precisely constructed on the microstrip.

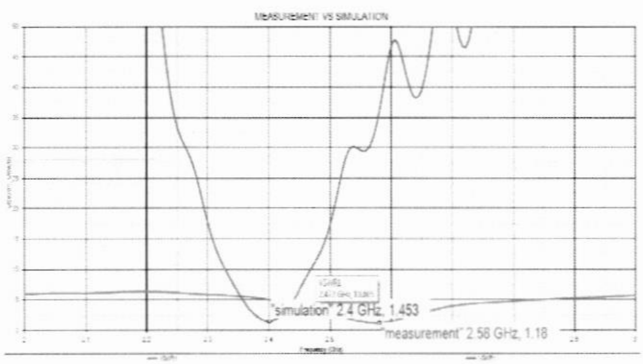

Fig 9: Simulated VSWR of Microstrip Array Antenna

E. *BANDWIDTH (BW)*

Fig.12 and Fig.13 show the simulated and measurement bandwidth of the antenna. The bandwidth of simulation microstrip antenna is obtained about 1.31% while the bandwidth of measurement obtained is 1.82%.This both of simulation and measurement result gives a bandwidth which is narrow bandwidth. It is because of the substrate using in this design is FR-4 and use coaxial probe.

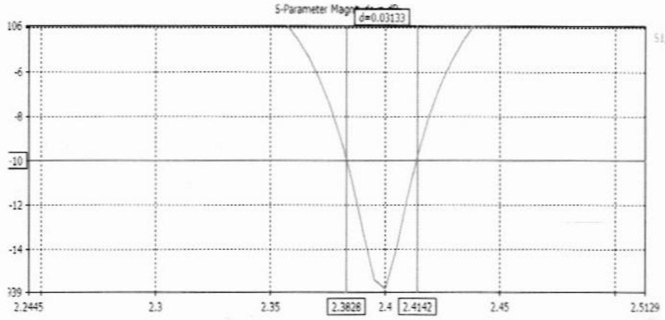

Fig 10: Simulated Bandwidth of Microstrip Array Antenna.

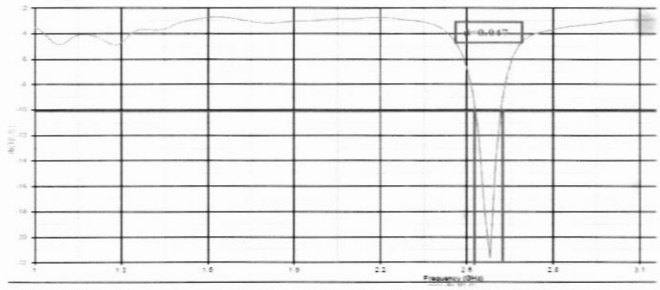

Fig 11: Measurement Bandwidth of Microstrip Array Antenna.

TABLE VII
SUMMARIZATION RESULTS OF 2 by 2 ARRAY ANTENNAS

Parameter	Simulation	Measurement	Deviation	%Deviation
Frequency, f_0	2.4 GHz	2.58GHz	0.18GHz	7.5%
S_{11}	-14.672	-21.657	-6.985	47.60%
BW	0.03133GHz	0.047GHz	0.01567GHz	50.02%

4.0 CONCLUSION

The 2 by 2 Rectangular Microstrip patch Array Antenna was developed based on the most basic principle of all microstrip patch antenna. Calculations were made to obtain the required measurement for the antenna's dimensions. Through the CST simulation, results were obtained. It was observed that the measured resonant frequency still closer to the simulation on value which is 2.4GHz. However, it was difficult to pin point specific factors responsible for the mismatch that mentioned in previous chapter. Normally the analysis microstrip patch array antenna strongly depends on several factors such as feeding technique, type of substrate, the thickness and dielectric constant of substrate respectively. As a conclusion although the designed antenna has a shifted about 7.5% in frequency, it still can be used as an access point since it still in the range of WLAN application acceptable frequency.

5.0 FUTURE DEVELOPMENT

It is recommended that several improvements are to be made in terms of the size of the patch chosen. Since in the advancement of technology, all electronic-related devices are reducing in size, therefore it is important for the sizes of these antennas to be reduced. The preferred substrate also needs to be wisely selected.

ACKNOWLEDGMENT

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