CHAPTER 4

RESULTS AND DISCUSSION

4.2 Introduction

In this chapter, the simulation and measurement results for microstrip single patch and array antenna are presented. The simulation is performed by using Microwave Office (MWO) software as a Computer Aided Design (CAD) tool. Based on these results, the layouts are obtained and then send for fabrication. After fabrication, the antennas will be test by using Agilent Network Analyzer and Wave and Antenna Training System (WATS 2002) equipment. The results will be discussed at the end of this chapter.

4.3 Characteristics Of Designed Antennas

This section will be focused to determine the characteristics of the designed antenna either it achieved the objective of this project which is to design 2.45 GHz microstrip patch array antenna for WLAN application. The characteristics that will cover are return loss response (S_{11}), Radiation Pattern and the ability of the antennas. The results obtained for simulation and measurement will be separate to single microstrip patch and microstrip patch array antenna.

4.4 Single Patch Microstrip Antenna

This section will be covered results for single patch antenna both simulation and measurement. The characteristics that have been focused are Return Loss (S_{11}) and radiation pattern. The results are separate into two sections which are in simulation result using Microwave Office and measurement results. As an addition, the network performance testing also performed to test the ability of the antenna in WLAN application.

4.4.1 Microwave Office Simulation

As mentioned in the previous chapter, the first step for using this software is to determine all the parameters of the substrate used. In this case, FR4 is used. The parameters are the dielectric substrate, thickness of conductor, tangent lost of conductor, surface roughness and the frequency that the patch will be resonant which are clearly visible in Figure 3.11.

MWO provide circuit and EM simulation, and support the designing of simple circuits to complex RF applications. Therefore simulation of the antenna is possible in MWO. After constructing the layout of the single patch antenna as describe at the Chapter 3, and illustrated in Figure 3.9. Then after simulation finish, the results for the simulation are shown in Figure 4.0. For the simulation, the result will be focused on return loss (S_{11}).

S_{11} is the input reflection coefficient and it is supposed to have the lowest dip at the operating frequency. S_{11} is equal to the ratio of the reflected wave and an incident wave with the load impedance (antenna impedance) equal to the line impedance. It measures the antenna's absorption of the fed power over the total power fed. A good antenna should indicate a return loss of less than -10 dB, which indicates that the antenna absorbs more than 90% of the fed power.

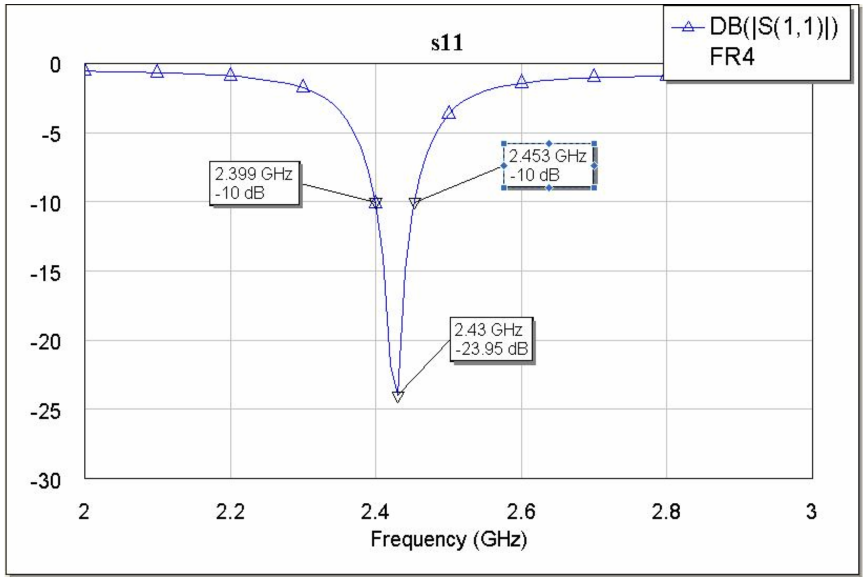

Figure 4.0: S_{11} Simulation Response for Original Single Patch Dimension

From the simulation response result, the S_{11} for single patch antenna is -23.95dB at 2.43 GHz. This result is not ideal with the objective in this project which is the resonant or operating frequency for the antenna suppose at 2.45 GHz. Therefore, optimization process need to be performed to improve the result as the calculated dimensions does not take the minor losses into considerations.

4.3.1.1 Optimization of Patch Antenna

Optimization process is performed manually in this project by adjusting various dimension of the patch such as width and length to achieve the desire operating frequency. From the theoretical that has been discuss in chapter 2 where by adjusting the width of the patch will affect the resonant resistance of antenna. For the antenna resonant frequency, determine by it length. To find out how the various dimensions of the patch antenna effect the operation of the antenna, the various dimensions were adjusted and the several results were recorded in Table 4.0.

Table 4.0 Various Dimension Effect on S_{11} Response

Patch (mm)		Frequency (GHz)	S_{11} (dB)
Width	Length		
36.26	27.90	2.43	-23.95
36.20	27.40	2.53	-26.13
36.26	27.70	2.48	-27.18
36.30	27.60	2.48	-24.49
36.27	27.55	2.46	-27.59
36.25	27.50	2.44	-27.20
36.25	27.60	2.45	-28.45

The table shows how the S_{11} is affected by the various dimensions of the patch antenna. From this, a clear understanding of what dimensions need to be adjusts to optimize the antenna in order to achieve the desired response.

Table 4.1: Optimise Dimension Versus Original Dimension (Single Patch)

Patch	Original size (mm)	Optimized size (mm)	Difference (mm)
Width	36.26	36.25	0.01
Length	27.90	27.60	0.30

From the Table 4.1 shows that the differences between the original and the optimized patch antenna are very small. This shows that the dimensions calculated are quite accurate. Therefore, the optimized patch antenna's dimensions are put to simulation and the simulation response is shown in Figure 4.1.

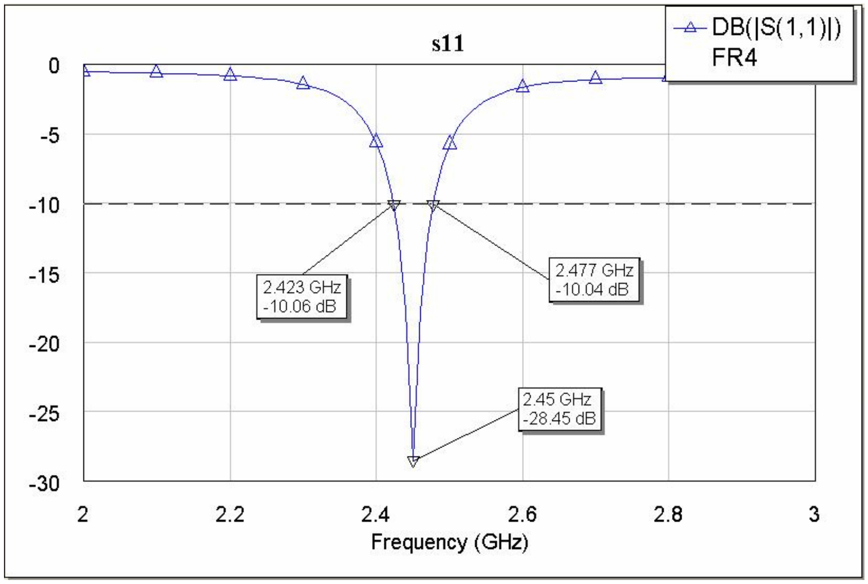

Figure 4.1: Optimize S_{11} Simulated Response

As can be seen, the resonant frequency of the patch is 2.45 GHz. The attenuation is at -28.45dB. Also the bandwidth of the patch at -10 dB is approximately 54 MHz. It can thus be seen that the resonant frequency achieved is exactly the same with the target frequency which the patch was designed to resonate at 2.45 GHz. The optimized dimension antenna can be referred in the Appendix A.

4.3.1.2 Radiation Pattern Simulation Result

The radiation pattern measures the capability of an antenna to receive or transmit in a certain direction. It also gives a measure of the gain and the half power beam width (*HPBW*), and directivity, which also works to achieve the same goal, which is to measure how an antenna performs at a specific direction. This can be determined when the polarization patterns for E and H plane are plotted. A good antenna should have a 0^o isolation of more than 20 dB, which is the difference between the co-polarized value and the cross-polarized value at 0^o.

.The radiation pattern basically is affected by the width of the patch, *w* and the substrate height, *h*. The smaller the value of *w*, the broader the H plane pattern will be, while the thinner substrate, *h*, broadens the E plane.

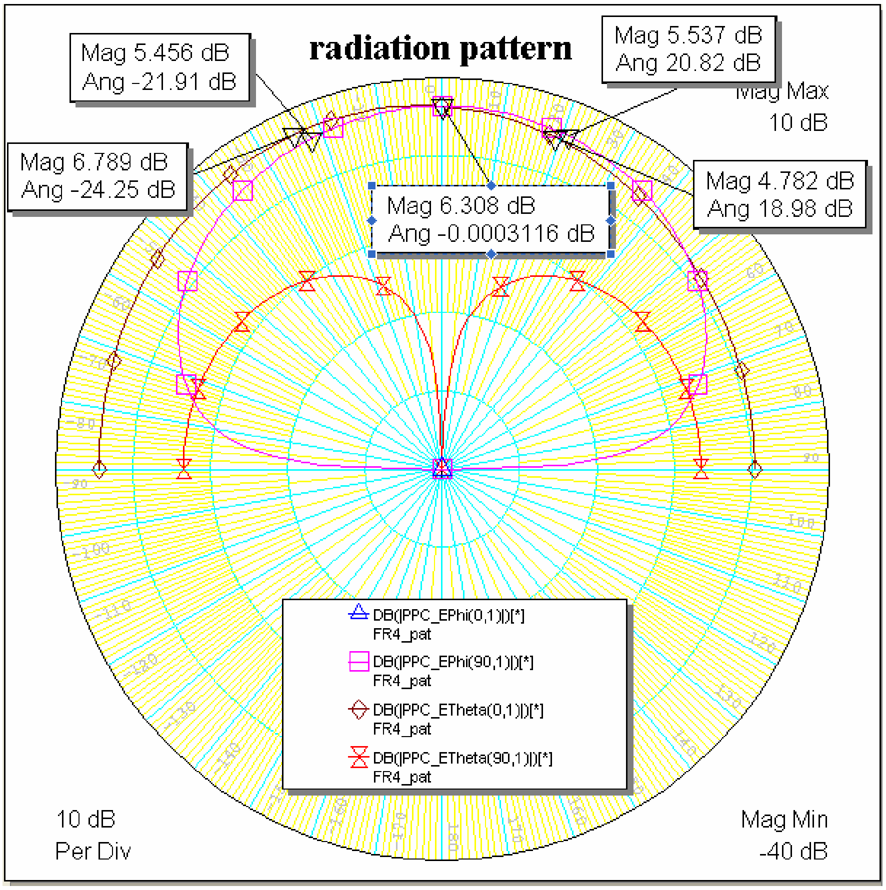

Figure 4.2: Single Patch Optimized Simulated Radiation Pattern

The simulated *HPBW* is 43.2^{o} for H plane while the E plane produced a *HPBW* of 42.73$^{o.}$ The *HPBW* for E plane is narrow caused by the thin substrate. In addition to that, the width of the antenna patch is larger, thus generating a larger beam width for the H plane. The simulated gain of the antenna is 6.308 dB.

4.3.2 Measurement Results

In this project, there are three main measurements to be taken with the antennas.

1. S_{11} measurement
2. Radiation pattern
3. NetStumbler Test

There are several equipments that are used for the measurements of the antenna. The equipments used are listed below.

Equipments list:

1. Agilent E5062A Network Analyzer (300 kHZ - 3 GHz)
2. Wave and Antenna Training System (WATS 2002)
3. Laptop with 3Com Wireless LAN card.
4. NetStumbler 0.4.0 software.
5. D-Link DI-524UP Wireless router

The testing and measurement results for the antennas are collected and plotted on graphs in data-processing software such as Microsoft Excel. For S_{11}, the data are collected using the network analyzer, while the radiation pattern data are collected using WATS 2002. For the network performance, the data is collected using NetStumbler software. The polar plots are generated using Microsoft Excel software.

4.3.2.1 S_{11} Measurement

The S_{11} of the antennas is taken with Agilent E5062A network analyzer. Basically the network analyzer is capable of measuring signals from 300 kHz to 3 GHz. For measuring of S_{11}, the setup of the equipment is fairly easy. The antenna is connected to the network analyzer through a SMA connector. The figure below shows the S_{11} measuring using the Agilent E5062A network analyzer.

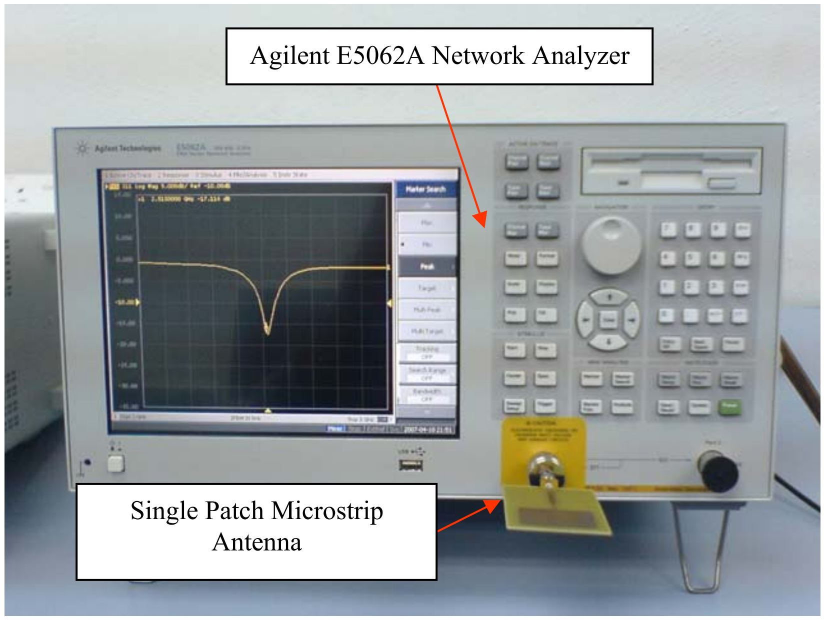

Figure 4.3: S_{11} Measurement Process Using Agilent E5062A Network Analyzer

The measured result is present in Figure 4.4. From the result, it found that the S_{11} frequency is 2.52 GHz at -24.70dB. The bandwidth of the measured antenna is about 65 MHz. The measured frequency result has a shifting that will be discussed in discussion section onward.

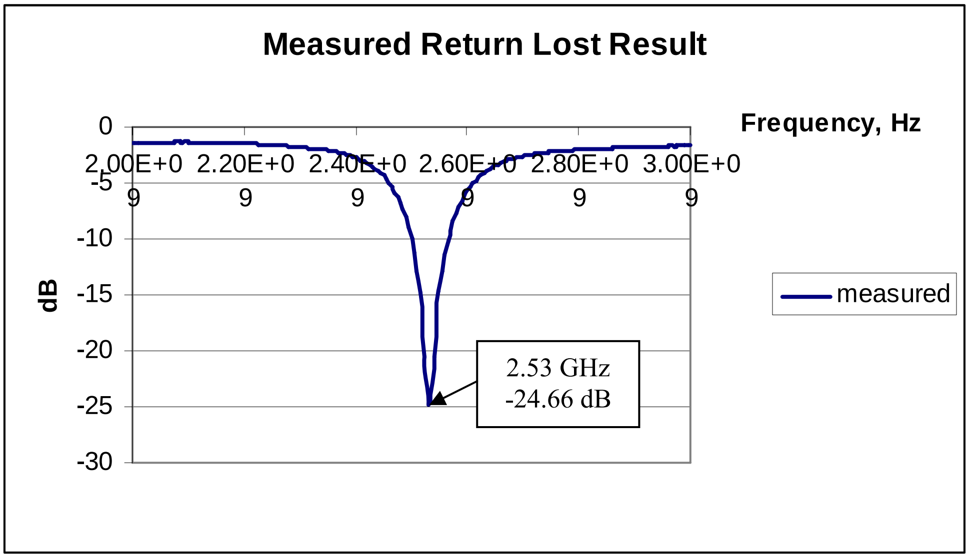

Figure 4.4: Measured S_{11} Result

4.3.2.2 Radiation Pattern Measurement

In this section will present the measurement results of radiation patterns plotted on a polar format. It was done using WATS 2002 equipment. Figure 4.5 show the measurement process. After that the result will be normalized and plot using Microsoft Excel in Figure 4.6. The radiation pattern will be measured both for the E plane and H plane.

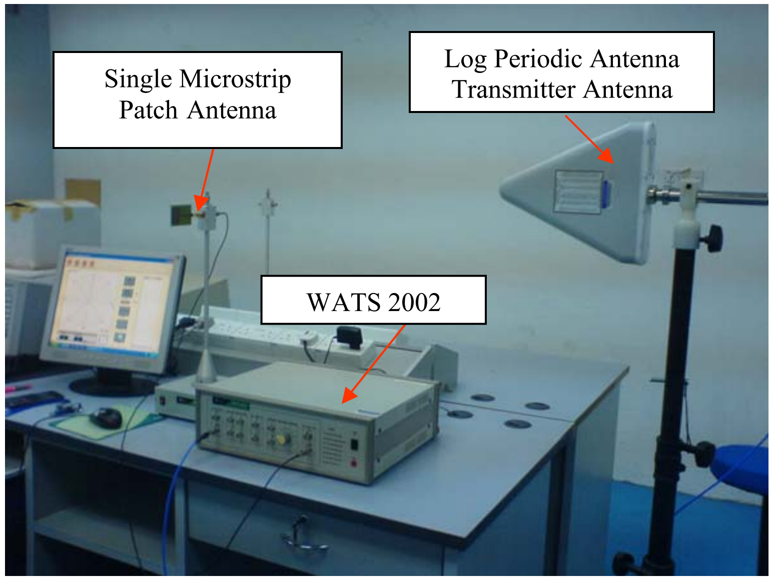

Figure 4.5: Single Patch Antenna Measurement Setup

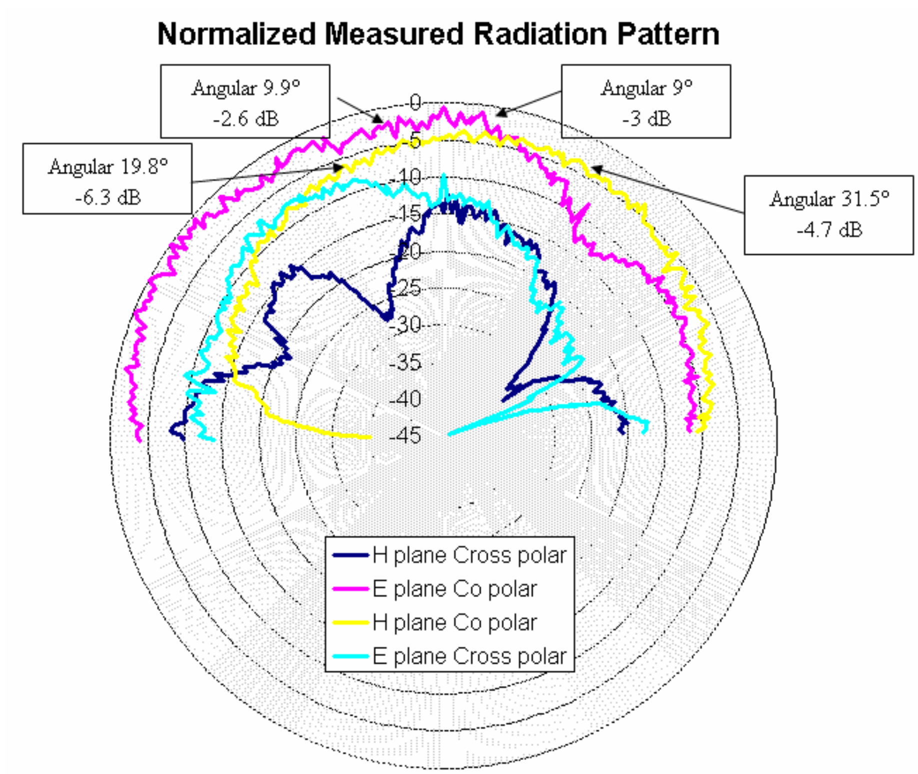

Figure 4.6: Measured Single Patch Radiation Pattern

From the figure, the *HPBW* for the E plane is only 19.9° only. For the H plane the *HPBW* is 51.3°. The measured result has a larger *HPBW* than simulated result for the H plane. However the E plane *HPBW* is narrower than simulated. The maximum cross polarization for H plane is -32.4 dBm and -27.8 dBm for co polarization. The 0^{o} isolation between both polarization patterns is 10 dB which satisfies the minimum threshold of 10 dB.

For the E plane, maximum co polarization is -24.2 dBm. The cross polarization for this antenna is large, which is -31.1 dBm. The 0^{o} isolation between both polarization patterns is 9 dB for E plane.

4.3.2.3 NetStumbler Test

In this section, the antenna will be test for it ability to transmit signal. The existing antenna at wireless router will be replaced with the single patch antenna. The antenna will be act as a transmitter antenna. Figure 4.7 and 4.8 show the testing arrangement of the equipment. The NetStumbler software will test on Signal to Noise Power Ratio (SNR).

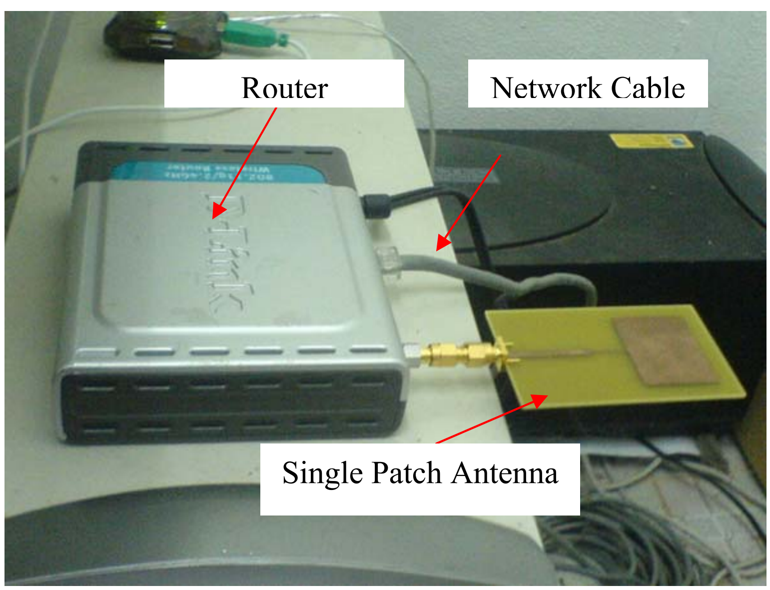

Figure 4.7: Wireless Router Setup for NetStumbler Test

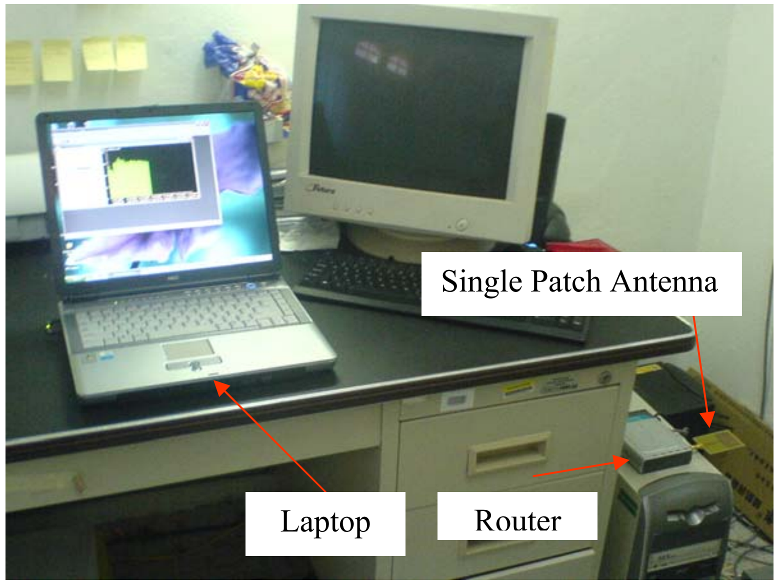

Figure 4.8: Single Patch Antenna NetStumbler Test Configuration

This testing will determine the ability of the antenna to be used in WLAN application. Two different environments have been performed for testing which is in the same room with the router and in the other room. A result that has been obtained is plotted by Signal to Noise Power Ratio, SNR against Time in Microsoft Excel. Figure 4.9 below shows the result for the single patch antenna. From the figure shows that the average SNR for single microstrip patch antenna is 28 dB

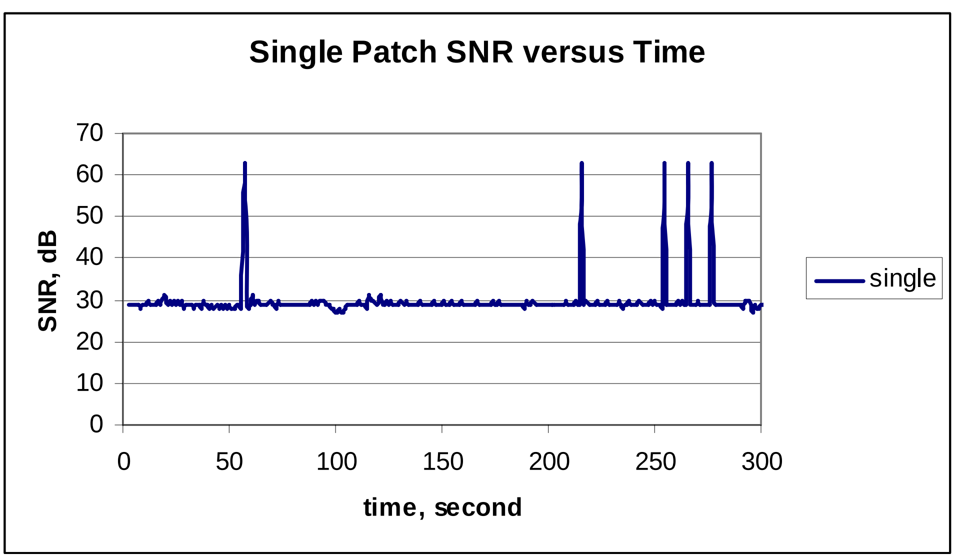

Figure 4.9: Single Patch Antenna NetStumbler Test Result

4.4 Microstrip Patch Array Antenna

In this section, the results for microstrip patch array antenna will be focused on S_{11} response, radiation pattern and network performance. For S_{11} response and radiation pattern, both simulation and measurement results are presented.

4.4.1 Microwave Office Simulation

The step for simulation array antenna is same with the single patch antenna that has been discussed previous. The step will be repeated for the array antenna. Figure 4.10 below show the result for S_{11} simulation response for the original dimension of array antenna.

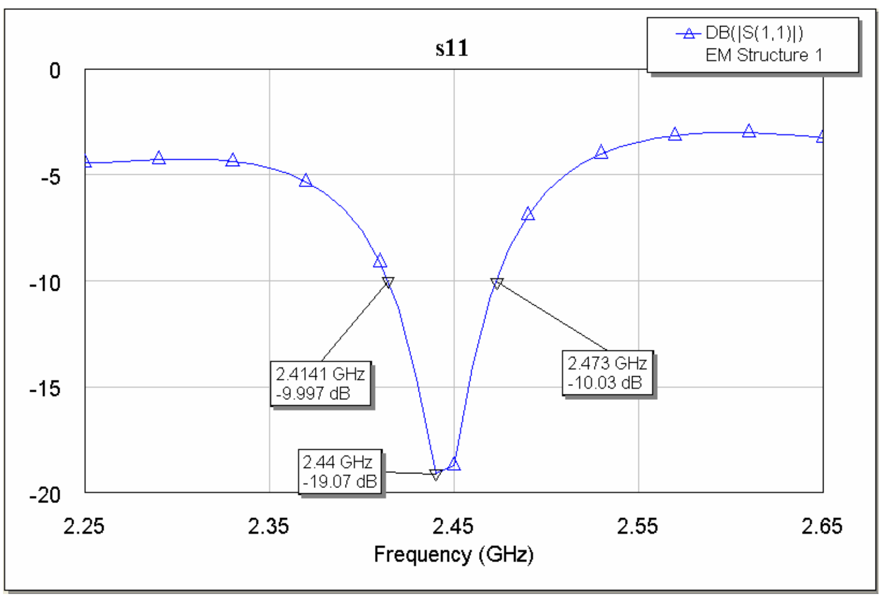

Figure 4.10: Simulated S_{11} Response for Original Array Antenna Dimension

From the figure, the resonant frequency is 2.44 GHz and the attenuation -19.07 dB. The antenna needs to be optimize in order to achieve the desire specification. It is because the calculated dimensions do not take the minor losses into considerations. The optimization process will be performs by adjusting the various dimensions of the antenna.

4.4.1.1 Optimization of Array Antenna

The Table 4.2 and Figure 4.11 show the difference size and optimized result for array antenna after adjusting various dimension of the antenna. From the result, the S_{11} has a lowest deep, -30.07 dB at the operating or resonant frequency 2.45 GHz. The bandwidth of the optimized antenna is approximately 70.3 MHz. The optimized dimension for array antenna is provided in the Appendix A(i).

Table 4.2: Optimize Dimension versus Original Dimension (Array Patch)

Patch	Original size (mm)	Optimized size (mm)	Difference (mm)
Width	36.26	39.00	2.74
Length	27.90	28.15	0.25

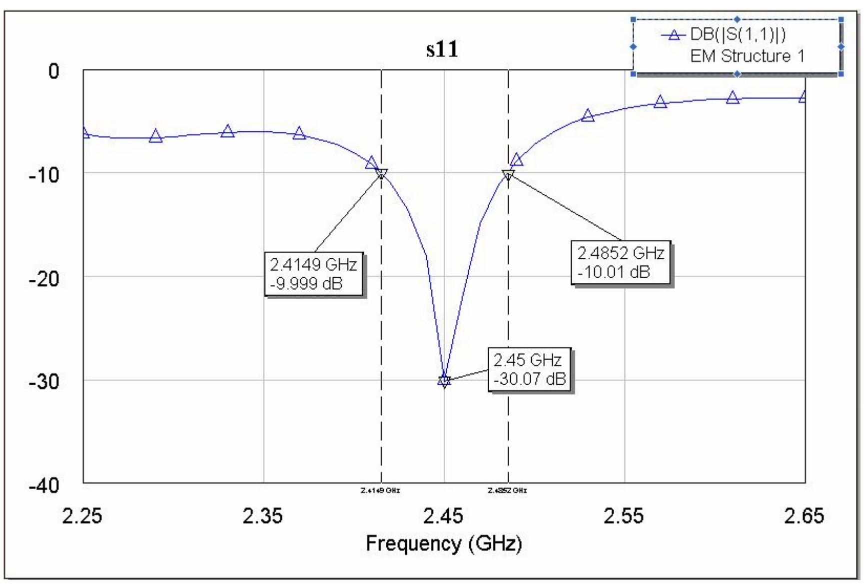

Figure 4.11: Optimize S_{11} Array Antenna Response

4.4.1.2 Radiation Pattern Simulation Result

The simulation result for optimized radiation pattern is illustrated in the Figure 4.12 below.

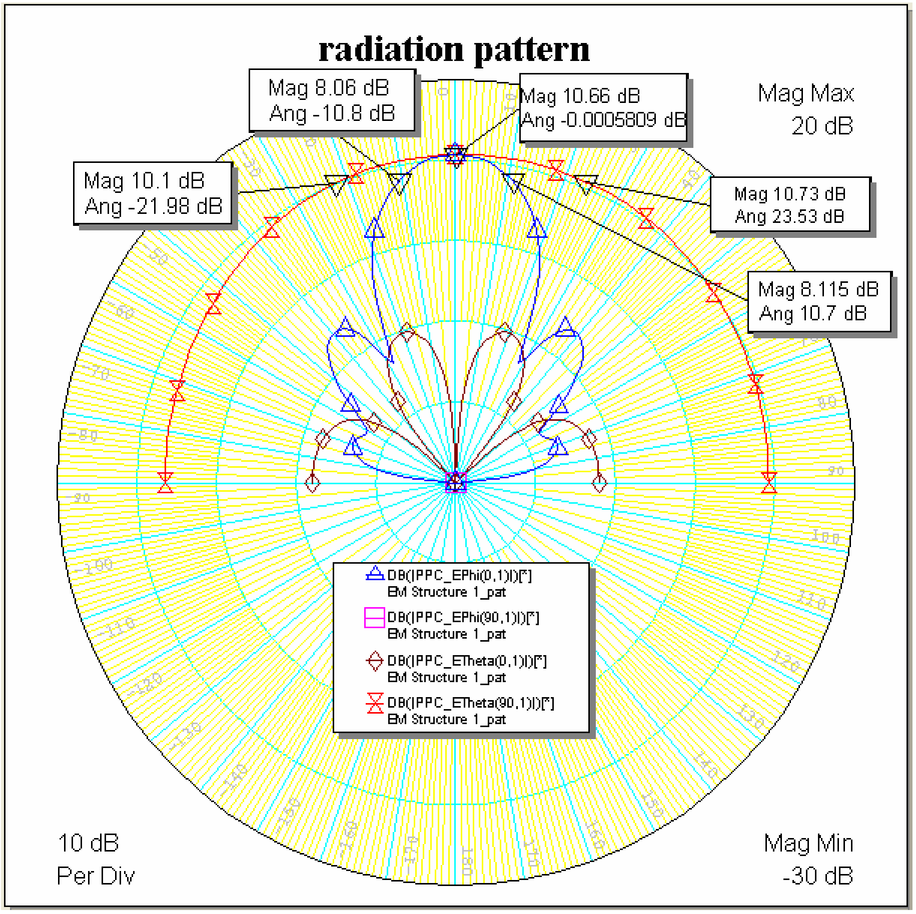

Figure 4.12: Optimized Simulated Radiation Pattern

From the result obtained, the *HPBW* for E plane is 45.51°. The H plane *HPBW* given by the simulated result is narrower than E plane which is 21.5°. The array antenna simulated gain from the radiation pattern approximately 10.66 dB.

4.4.2 Measurement Result

The measurement for the array antenna is using the same equipments as in single patch antenna. The parameter that involved in this measurement is S_{11} response, radiation pattern and network performance.

4.4.2.1 S_{11} Measurement

The Figure 4.13 below shows the measured S_{11} response for microstrip patch array antenna that has been designed. From the figure found that the S_{11} response drop at 2.52 GHz within -20.15 dB. The measured bandwidth for the array antenna is approximately 0.11 GHz.

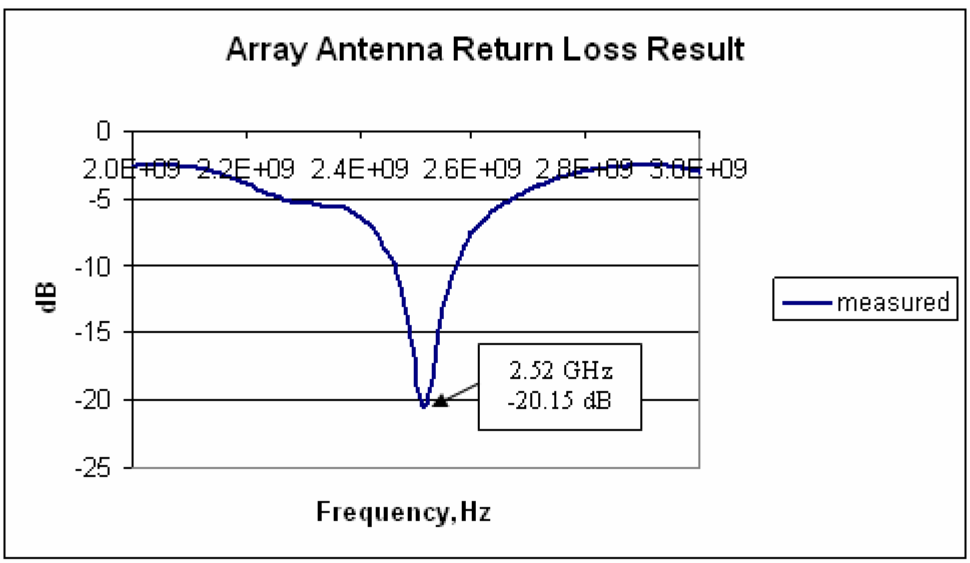

Figure 4.13: Measured S_{11} Response for Array Antenna

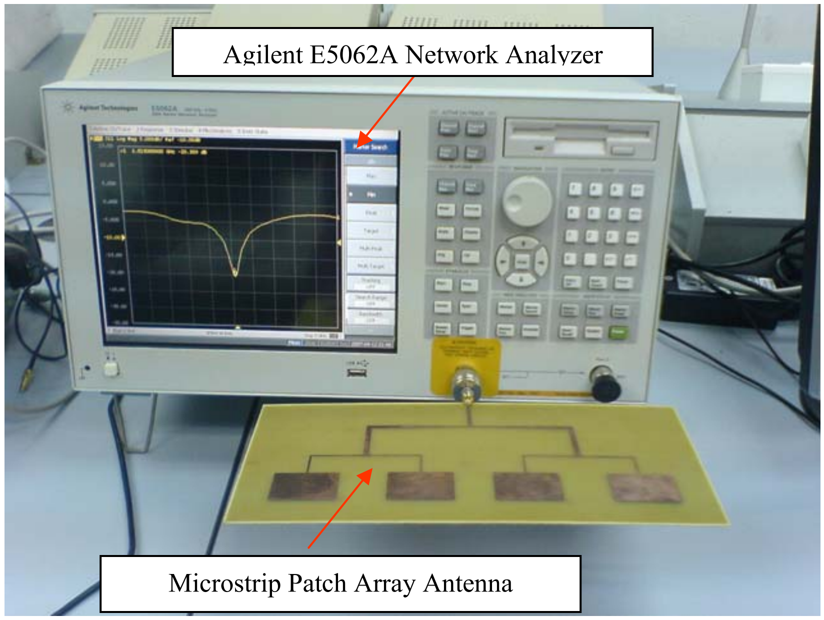

Figure 4.14: S_{11} Measurement Process for Array Antenna Using Agilent E5062A Network Analyzer

4.4.2.2 Radiation Pattern Measurement

The measurement process for radiation pattern is illustrated in Figure 4.15. The testing using Log Periodic Antenna (LPA) as a transmitter antenna. Both cross and co polarization for E plane and H plane are measured and plotted. Measured radiation pattern of microstrip patch array antenna is presented in Figure 4.16.

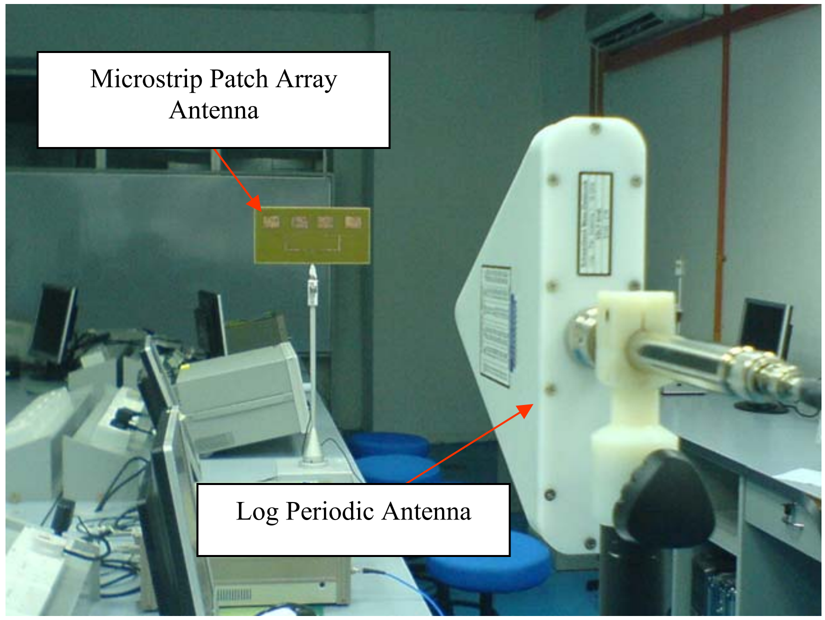

Figure 4.15: Radiation Pattern Measurement Setup for Array Antenna

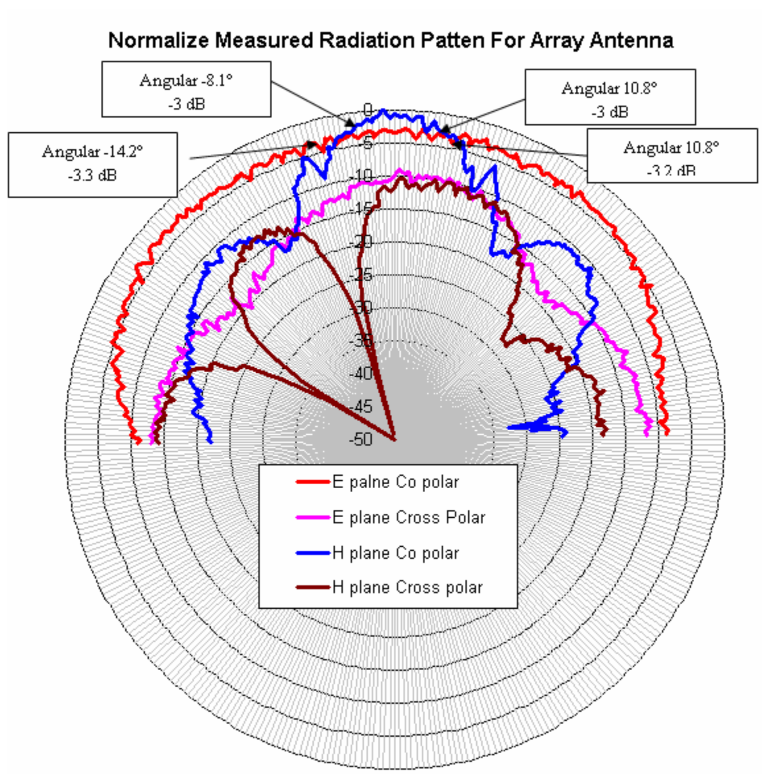

Figure 4.16: Measured Radiation Pattern for Array Antenna

The measured *HPBW* for H plane is 18.9° and the maximum co polarization is -7.8 dBm. The maximum cross polarization is -18.2 dBm. The measured radiation pattern produced 11.1 dB for maximum 0° isolation for the H plane.

On the other hand, the E plane produced a maximum co polarization of -10.4 dBm while the maximum cross polarization value is -17 dBm. This produces a nominal isolation of 7.8 dB. The *HPBW* of this measurement on this plane is 25^{o}.

4.4.2.3 NetStumbler Test

After performed S_{11} response and radiation pattern measurement, the antenna will be test for it application which is use in WLAN. The objective of this test is to determine the ability of this antenna to transmit data over a network. The antenna is placed at wireless router as a transmission element. The figures below shows the testing set up and results.

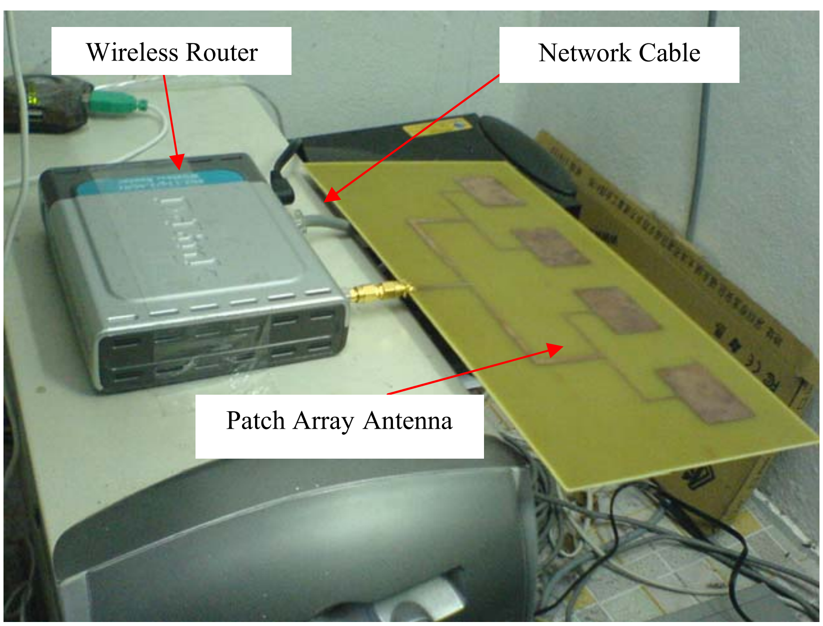

Figure 4.17: Wireless Router Setup for Array Antenna

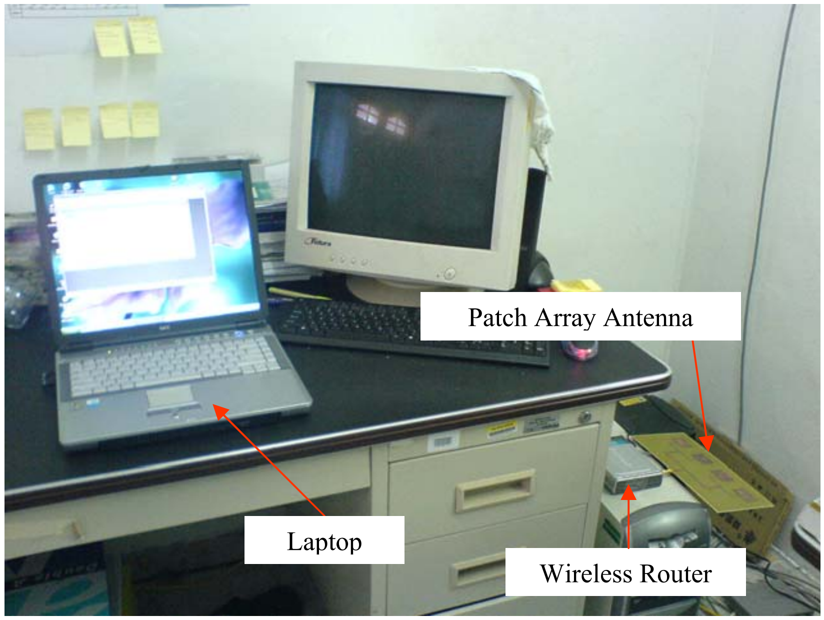

Figure 4.18: Microstrip Patch Array Antenna Netstumbler Testing Configuration

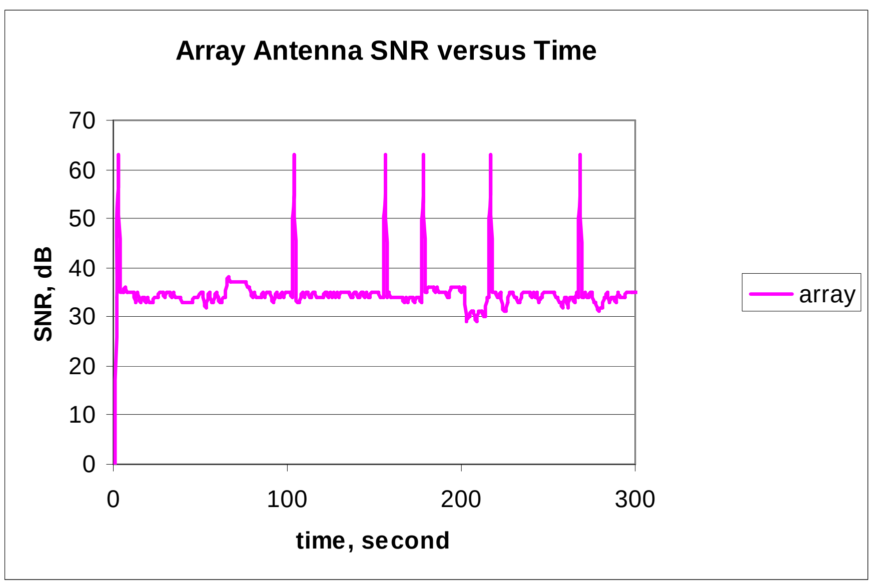

Figure 4.19: SNR versus Time for Patch Array Antenna

From the result obtained in Figure 4.19, the average Signal to Noise Power Ratio for microstrip patch array antenna is 35 dB.

4.5 Discussion

The results for measurement that has obtained at the previous section will be compared with the simulation results. The discussion for the results is present in this section base on the simulation result. The difference between those results for return loss, radiation pattern and network performance will be discussed briefly.

4.5.1 S_{11} Response

S_{11} simulation response is plotted against the measured response and illustrated in the Figure 4.20.

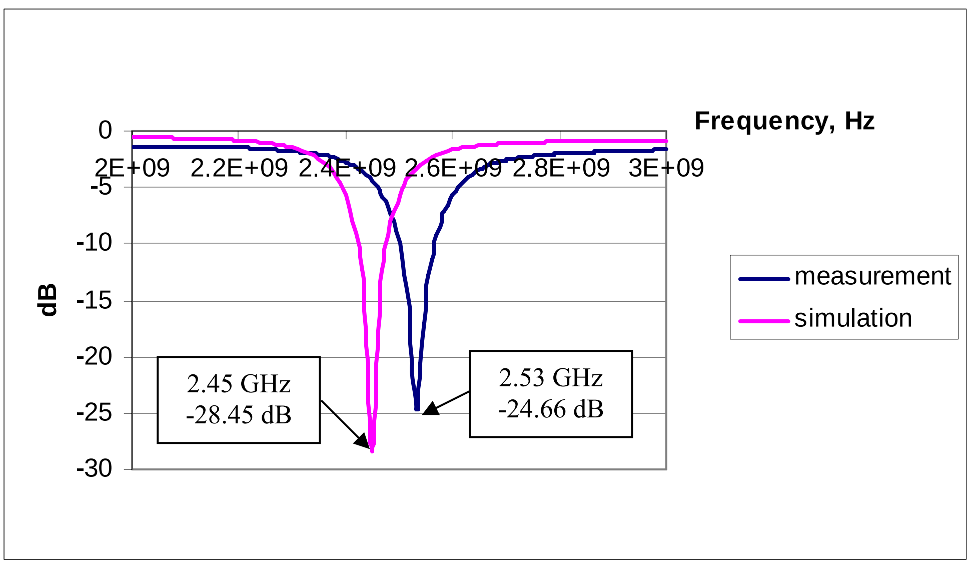

Figure 4.20: Single Patch Antenna S_{11} Response Simulation versus Measurement

From the figure above, found that the shifting frequency between simulation and measurement result is 3.27%.with a difference of 3.79dB. For the bandwidth (*BW*), the measured result is wider than simulated which about 20.37%. This is caused by the position of the feed line, which is etched on the same layer as the patch, and suffers from serious spurious radiation. Table 4.3 shows the summarized of the results.

Table 4.3: Summarization of the Single Patch Antenna

Parameter	Simulation	Measurement	Deviation	% Deviation
Frequency, *f*	2.45 GHz	2.53 GHz	0.08 GHz	3.27
S_{11}	-28.45	-24.66	3.79 dB	-13.32
BW	0.054 GHz	0.065 GHz	0.011 GHz	20.37

The microstrip array antenna S_{11} response and summarization are shown in figure and table below. The summarization of the array patch is illustrated in Table 4.4.

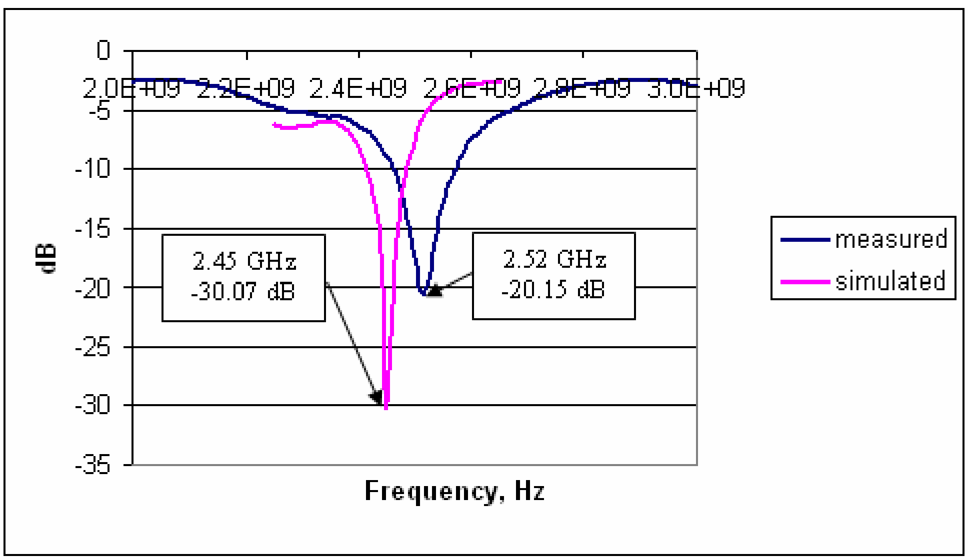

Figure 4.21: Array Antenna S_{11} Response Simulation versus Measurement

Table 4.4: Summarization of the Array Patch Antenna

Parameter	Simulation	Measurement	Deviation	% Deviation
Frequency, *f*	2.45 GHz	2.52 GHz	0.07 GHz	2.86
S_{11}	-30.07 dB	-20.15 dB	-9.92 dB	32.99
BW	0.0735 GHz	0.11 GHz	0.0365GHz	49.66

The shift frequency for array antenna is about 2.86 % with a difference of -9.92 dB. The difference between simulated and measured result for bandwidth is approximately 49.66 %. The measured bandwidth obtained is 0.11 GHZ.

For the both single patch and array antenna result, various factors such as incorrect design procedures, inaccuracy of the MWO design software, poor fabrication or incorrect measurement process and environment could affect the results. In this project, the accuracy of return loss measurements also depends on two circumstances which are environment of measurement and the characteristics of the equipments used.

The equations that are used could not be wrong as the measured response is very near to the simulated response. MWO accuracy could be verified by fabrication of the various dimensions antennas listed in Table 4.0 and then compare their measured response to the simulated response. However, this is not feasible as it very costly to fabricate more antennas.

As mention previous in chapter 3, the dielectric constant value might not be exactly at 4.7 at 2.45 GHz, but with the measured response close to the simulated response, the value 4.7 used should be fairly accurate. Poor fabrication process might lead to inaccuracy of measurements, as a high level of accuracy is needed for microstrip circuitries. The fabrication need the high level of accuracy maintained when fabricating the microstrip antennas.

Another factor that leads to process deviation was that substrate manufacture at different batches tends to have a slight variation in its properties. After all these analyzing, the problem lies either with the MWO software or the substrate.

The MWO might be the problem because the accuracy of the software depends on the cell size that defined by user. The smaller of the cell size giving more accurate and smooth result. However, when the size of cell gets smaller, it wills takes long period of simulation process. It is because the software needs to perform the more calculation. In order to find out the accuracy of the software, the simulation of the single patch antenna is performed using difference size of cell. One patch is using 1 mm x 1 mm for x and y position and another 0.5 mm x 0.5 mm cell size. The result that obtained is clearly visible in Figure 4.22.

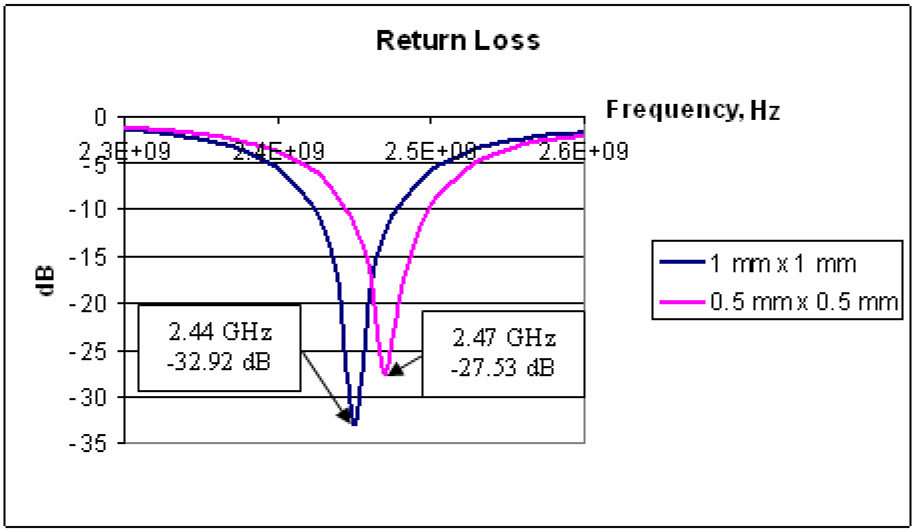

Figure 4.22: Comparison of Cell Size Effect for Simulation

From the figure shows that the result is different from each other even the patch dimensions that use for simulation is similar. Here it can be assume that the MWO is not entirely accurate. The most probable reason is that MWO does not sufficiently compensate the effects of open end discontinuity. The larger the patch size, the larger the open end discontinuity and the larger the inaccuracy. As in most simulation software there will be some minor difference between the simulated results as compared to the measured result, MWO is no exception.

4.5.2 Radiation Pattern

The summarization of the simulated and measured radiation pattern is show in Table 4.5. It is also shown from the measurement result in table that the directivity produced by a certain type of antenna is very much dependant of the E plane *HPBW*. The smaller the *HPBW* is for the E plane, the more directive the antenna becomes. The array antenna is more directive since it *HPBW* is narrower than single patch antenna and it equal with the theoretical. However, the measured radiation pattern is not 100 % accurate since the measurement process is not carry out in anechoic chamber. It can be seen in the result that the radiation pattern have a noise interference. It is because if the measurement process performs inside the anechoic chamber, it will reduce and minimize the interference. The anechoic chamber will absorb the signal without reflected it back. The reflected signal will generate multipath fading effect.

Therefore, the measured results for both single patch and array antenna are not so smooth because affected by reflections from its surroundings especially a good radiator such as metal.

Table 4.5: Summarization of the Radiation Pattern

Parameter	Measurement			
	Single Patch		Array Patch	
	H- Plane	E- Plane	H- Plane	E- Plane
Maximum co polarization (dBm)	-27.8	-24.2	-7.8	-10.4
Maximum cross polarization (dBm)	-32.2	-31.1	-18.2	-17
0° Isolation (dB)	10	9	11.1	7.8
HPBW	51.3°	19.9°	18.9°	25°

4.5.3 NetStumbler Result

The signal to noise ratio power for single patch and array antenna is illustrated in figure below. From the result, it shows the array antenna has higher SNR if compare with the single patch antenna. The microstrip array antenna has an average about 35 dB SNR rather than single patch antenna which is only 28 dB. The higher the signal to noise power ratio, the better the performance and the higher the information capacity. [17]

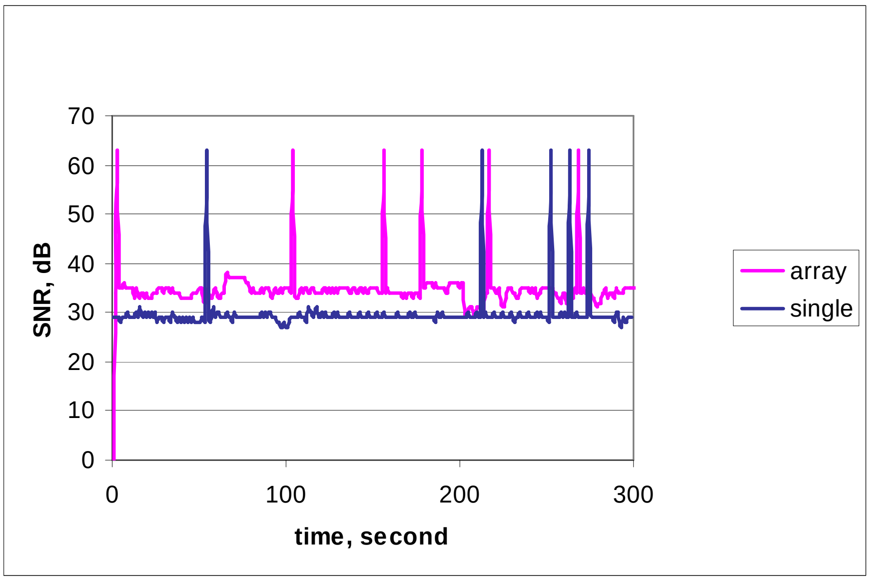

Figure 4.23: Comparison of SNR between Single Patch and Array Antenna

Therefore, it can be summarized that the performance of microstrip patch array antenna is better than single microstrip patch antenna. The array antenna is more directive and has a higher gain which made it more efficient than single patch.