Microstrip Rectangular Patch Antenna at 2.5GHz

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Abstract — **This paper presents the design of microstrip rectangular patch array antenna with operating frequency at 2.5GHz for WiMAX application. The array of 4x1 microstrip rectangular patch antenna with microstrip line feeding based on quarter-wave impedance matching technique was designed and simulated using CST Microwave Environment software. The performance of the designed antenna was analyzed in term of return loss, VSWR, bandwidth, directivity, radiation pattern and gain. The antenna was then fabricated on the substrate type FR-4 with dielectric constant of 4.9 and thickness of 1.6mm respectively. The antenna was measured in the laboratory using Vector Network Analyzer (VNA) and the results show good agreement with the simulated performances.**

***Keywords*- Microstrip Antennas, Array Antenna, Microstrip Line Feeding, substrate FR-4, CST.**

I. INTRODUCTION

These days, there is a very large demand for wireless applications. Antennas which are used in these applications should be low profile, light weight, low volume and broad bandwidth [1]. To meet these requirements, microstrip antenna is preferred. This antenna is low-profile, comfortable to planar and nonplanar surfaces, simple and inexpensive to manufacture, mechanically robust when mounted on rigid surfaces and when the particular patch shape and mode are selected they are very versatile in terms of resonant frequency, polarization, pattern and impedance [2]. Although microstrip antenna has several advantages, it also has several disadvantages such as low gain, narrow bandwidth with low efficiency. These disadvantages can be overcome by constructing many patch antennas in array configuration [3].

Wireless communication has experienced an enormous growth since it allows user to access network with no worries of the burden of wires infrastructures. Also, people today are very keen to the high capacity mobile accesses of network services which the access speed rate are the priority over the others. WiMAX which means Worldwide Interoperability for Microwave Access is one of the answers of this matter. It is a telecommunications technology that provides wireless transmission of data using a variety of transmission modes, from point-to-multipoint links to portable and fully mobile internet access. The technology is based on the Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard. At now, just two WiMAX system profiles are outlined. The first one is the fixed WiMAX [4] is based on the IEEE 802.16d standard (also known as IEEE 802.16-2004) and substantially centered on the implementation of fixed, high bandwidth wireless links with low transceiver complexity. The second one is the mobile WiMAX [5] which is a version based on the IEEE 802.16e amendment (IEEE 802.16-2005), optimized for dynamic mobile radio channels and able to provide support for handoffs and roaming. These bring to the crucial responsibility to the antennas. Besides, being a platform of interrelation of transmitting and receiving the signal, they should be the champion in term of compact structure and ease of installation in various devices [6].

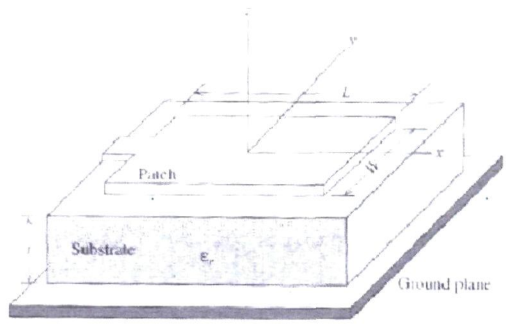

Fig. 1: General view of rectangular patch antenna.

II. SCOPE OF WORK

The work was limited to design four elements of microstrip rectangular patch antennas array with microstrip line as feeding method. Quarter-wave transformer is used to match the feeding line to the antennas. The operating frequency is determined to operate at 2.5 GHz. The antenna design is using FR4 as the substrate with thickness of 1.6mm.

Table 1: Microstrip patch antenna design specifications

Centre frequency, f_0	2.5 GHz
Return Loss	< -10 dB
VSWR	1
Other Scopes	Radiation Pattern, Directivity and Gain of Array Antenna

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III. METHODOLOGY

Fig. 2 shows the flowchart of the project. Literature review was done to obtain information of microstrip rectangular patch antenna. CST Microwave Environment was used to design and simulate to obtain the results. Antenna was then fabricated after the desired response of the simulation results was obtained. The fabricated antenna was tested in the laboratory and analyzed by doing comparison to the simulation results.

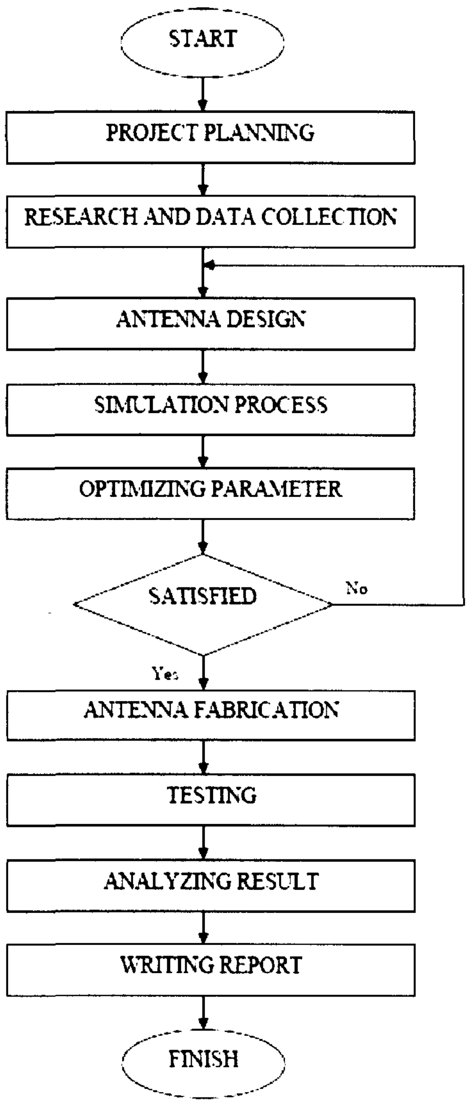

Fig. 2: Flowchart of antenna design

IV. ANTENNA DESIGN

After identifying the application that using frequency of 2.5GHz, the next step of antenna designing is to choose a suitable dielectric substrate of appropriate thickness and loss tangent. There are numerous substrates that can be used for the design of microstrip antenna and their dielectric constants are usually in the range of $2.2 \leq \varepsilon r \leq 12$. The ones that are most desirable for antenna performance are thick substrate whose dielectric constant is in lower end of the range because they provide better performance compared to thin substrate [3]. RT Duroid 5870 was originally chosen as the substrate as it has a low loss tangent which will not reduce the antenna efficiency, and has a relatively low dielectric constant. But, it was replaced by FR4 as the cost of using RT Duroid 5870 is too high. FR4 in comparison has a higher dielectric constant which results in a smaller patch size but the high tangent loss will result in lower gain. However, after going through the process of simulations, the results show that FR-4 meet the antenna specifications. With all these considerations, finally the proposed of single patch antenna design was established and the specifications are listed in Table 2.

Table 2: Design specification for single patch antenna

Operating Frequency, f_0	2.5 GHz
Substrate	FR-4
Dielectric Constant	4.9
Loss Tangent	0.025
Substrate Height	1.6 mm
Copper Thickness	0.035 mm

A. Single Microstrip Patch Antenna Design

The objective of this part is to design a single microstrip patch antenna which consists of patch, quarter-wave transformer and feedline. The design of microstrip rectangular patch antenna is beginning by determine its patch dimension. In order to do so, these following equations are used. The width and length of the patch are given as follow [6]:

$$w = \frac{c[1/\sqrt[2]{(\varepsilon r+1)/2}]}{2fo} \quad (1)$$

The length of the patch:

$$L = \frac{c}{2fo\sqrt{\varepsilon e}} - 2\Delta L \quad (2)$$

where

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+12d/W}} \quad (3)$$

and

$$\Delta L = 0.412h\frac{(\varepsilon_e+0.300)(\frac{W}{h}+0.264)}{(\varepsilon_e-0.258)(\frac{W}{h}+0.800)} \quad (4)$$

Since a 50 Ω surface mount adapter (SMA) connector is going to be used to connect the feedline to the coaxial cable, the feedline will be a 50 Ω feedline. The feedline will be feed to the patch through a quarter-wave transformer matching network [8]. Fig. 3 below shows a single microstrip patch antenna which consists of patch, quarter-wave transformer and feedline.

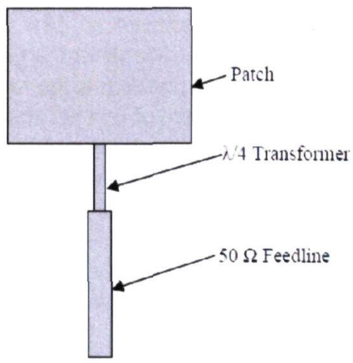

Fig. 3: Patch antenna with quarter-wave transformer

The impedance of the quarter-wave transformer is given by (5) [8]:

$$Z_1 = \sqrt{Zo(Rin)} \quad (5)$$

Where Z_1 is the transformer characteristic impedance and Z_0 is the characteristic impedance (real) of the input transmission line (50 Ω). *Rin* is the edge resistance at resonance. *Rin* can be calculated by using (6)[8]:

$$\text{Rin} = \frac{1}{2\text{Ge}} \quad (6)$$

where

$$\text{Ge} = 0.00836 \frac{\text{w}}{\lambda\text{o}} \quad (7)$$

Ge represent of edge conductance [8].

Next, for the width and length of the quarter-wave transformer and 50 Ω feedline are determined by the [7]:

$$W/d = \frac{8e^A}{e^{2A}-2} \ldots\ldots\ldots\ldots \quad \text{for } W/d < 2 \quad (8)$$

$$W/d = \frac{2}{\pi}[\text{B-1-ln}(2\text{B-1}) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\{\ln(\text{B-1}) + 0.39 - \frac{0.61}{\varepsilon_r}\}] \ldots\ldots\ldots\ldots \quad \text{for } W/d > 2 \quad (9)$$

where $$A = \frac{Z_O}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_{r+1}}(0.23 + \frac{0.11}{\varepsilon_r}) \quad (10)$$

$$B = \frac{377\pi}{2Z_O\sqrt{\varepsilon_r}} \quad (11)$$

$$L = \frac{\emptyset c}{2\pi f\sqrt{\varepsilon_e}}, \quad (12)$$

B. Microstrip Patch Array Antenna Design

The corporate feed network is chosen for designing four element array networks. The array antenna consists of a branching network of two-way power dividers [8]. Quarter-wave transformers (70 Ω) are used to match the 100 Ω lines to the 50 Ω lines. Fig. 4 below shows the impedance for individual lines in the four element rectangular array antenna.

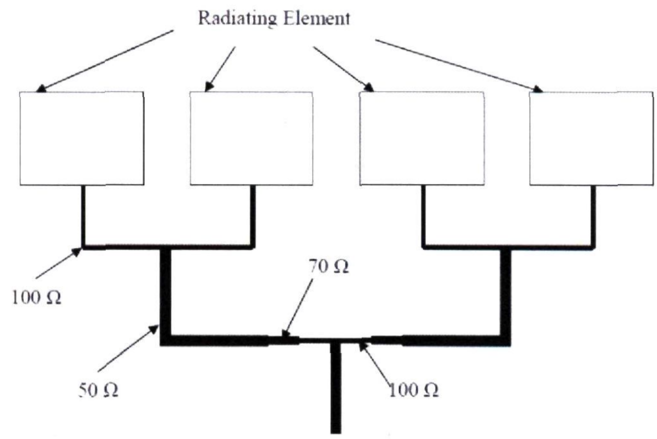

Fig. 4: Four elements array line impedance design layout

Similarly, the patch dimensions are obtained through equations (1) and (2). Calculation for impedance is also similar as a single patch calculation by using (5) to (7). However to matching the 100 Ω to 50 Ω transmission lines, the calculation step is shown below. Using the (5), where by replacing Z_o= 50 Ω and R_{in} = 100 Ω, the transformer characteristic impedance is [8]:

$$Z_1 = \sqrt{50(100)}$$
$$= 70\,\Omega$$

All impedance dimensions for 50 Ω feedline, 70 Ω quarter-wave transformer and 100 Ω impedance line are obtained by using the same (8), (9) and (10). Table 3 below show all the dimension of microstrip line impedance:

Table 3: Microstrip line impedance dimension

Impedance	Width (mm)	Length (mm)
50 Ω	2.81972838665	31.4148952545
70 Ω	1.49951007804	16.0936173639
100 Ω	0.621675421686	33.0522605069

C. CST Simulations

The table below shows some variation of the designs and comparisons were made in order to choose the best and final design. Since, the desired design is the array configuration, thus the simulations for single antenna were not very extensive. The single patch antenna design is needed for performance comparison with the patch array antenna. Thus, the extent of effectiveness of array configuration can be observed when comparing both types of configuration. Besides that, it will be necessary to vary the patch width, length and other parameter such as length of microstrip line of 100 Ω in order to optimize the performance of antenna. As so that, the best result for single patch antenna design is the blue-in-colour highlighted row and the yellow-in-colour highlighted row is chose to be the best design of the microstrip rectangular patch array antenna. After all this calculation and consideration has been taken to account, both antenna were simulated using CST Microwave software. The patch array antenna then was fabricated.

Table 4: Design specifications

Types of Antenna		Patch Width, W (mm)	Patch Length, L (mm)	S11 (dB)	VSWR	Radiation Efficiency, η (dB)	Directivity (dBi)	Gain (dB)
Single	From Calculation	34.93	26.78	-2.6424	6.6248	-5.520	6.465	0.945
	Length Adjustment	34.93	27.0	-2.1873	7.9841	-6.085	6.551	0.466
		34.93	26.0	-7.3428	2.5051	-4.937	6.123	1.186
		34.93	25.48	-15.315	1.414	-5.061	5.898	0.837
		34.93	25.0	-8.6207	2.9177	-5.160	5.571	0.411
	Width Adjustment	35.5	26.78	-9.6451	1.9825	-4.927	6.056	1.129
		34.5	26.78	-10.161	1.9003	-4.978	6.026	1.048
		34.0	26.78	-10.708	1.8227	-4.993	6.011	1.018
		33.0	26.78	-11.285	1.750	-5.046	5.984	1.186
4x1	From Calculation	34.93	26.78	-4.7278	3.7647	-6.406	9.770	3.364
	Length Adjustment	34.93	27.0	-4.3415	4.0843	-6.892	9.788	2.896
		34.93·	26.0	-7.9266	2.3416	-5.032	· 9.892	4.86
		34.93	25.1	-20.24	1.2155	-4.518	10.25	5.732
		34.93	25.0	-19.404	1.2399	-4.571	10.29	5.714
	Width Adjustment	35.5	26.78	-4.8298	3.6890	-6.515	9.745	3.23
		34.5	26.78	-4.866	3.6629	-6.444	9.718	3.274
		34.0	26.78	-4.9227	3.6131	6.391	9.709	3.30
		33.0	26.78	-4.9709	3.5895	-6.383	9.700	3.317

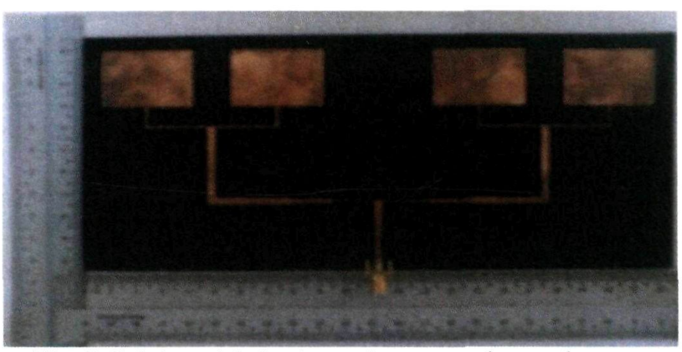

Fig. 5: Fabricated 4x1 microstrip rectangular patch array antenna

V. RESULTS AND DISCUSSIONS

Fig. 6 shows the return loss of microstrip patch antenna array in dB for both simulation and measurement. The simulation result gives a return loss of -20.24 dB at operating frequency 2.5GHz while the measurement result gives a return loss of -22.22 dB at 2.67GHz. The flaw during the fabrication process may leads to the shift of the operating frequency of measurement result. The return loss graph of measurement has been shifted about 6.8% from its original operating frequency.

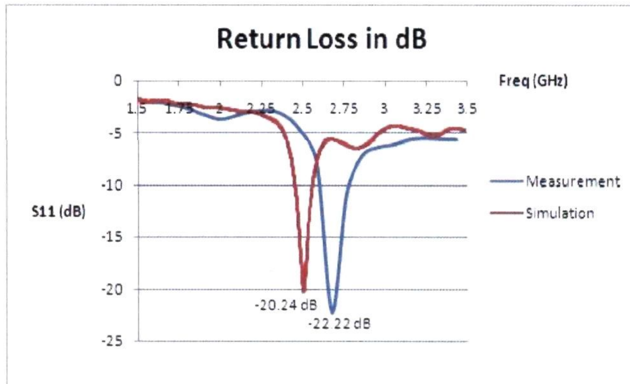

Fig.6: Return loss of simulation result

Fig. 7 and 8 show the bandwidth for both single and array antenna. Refer to fig. 7, the bandwidth of single antenna estimated is about 2.56%. Meanwhile, for the bandwidth of patch array antenna, the percentage is increase to 4.11%. This shows that microstrip antenna has shortcomings in terms of narrow bandwidth. But, it is also proven in the result below, this setback can be counter by constructing many patch antennas array configuration as suggested in theoretical part.

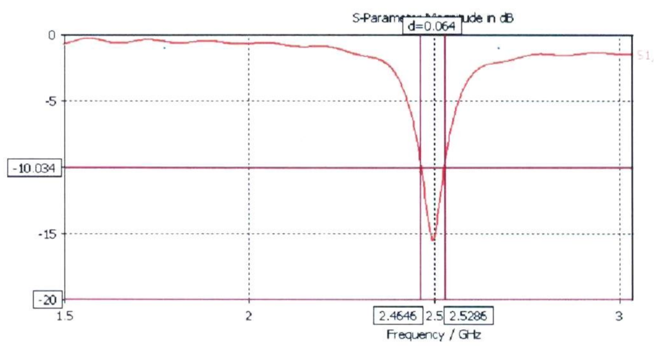

Fig. 7: Bandwidth of single patch antenna

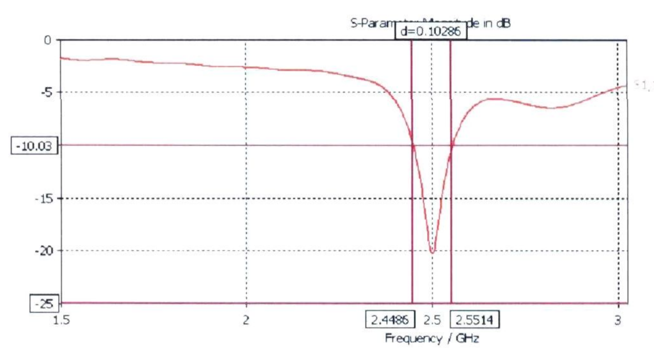

Fig. 8: Bandwidth of patch array antenna

Fig. 9 is the simulation result of voltage standing wave ratio. At centre frequency 2.5GHz, the VSWR value is 1.215. Fig. 10 on the other hand is the VSWR of measurement which portrays the VSWR is about 1.114 at frequency of 2.66GHz. Since, when concerning the effect of losses and errors that could happen in fabrication, this result could still achieve a good fabrication result.

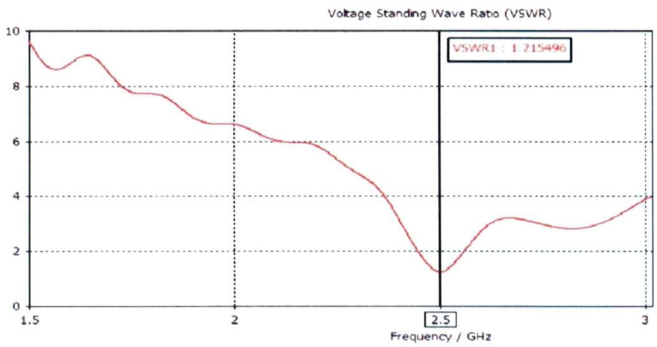

Fig. 9: VSWR of simulation result

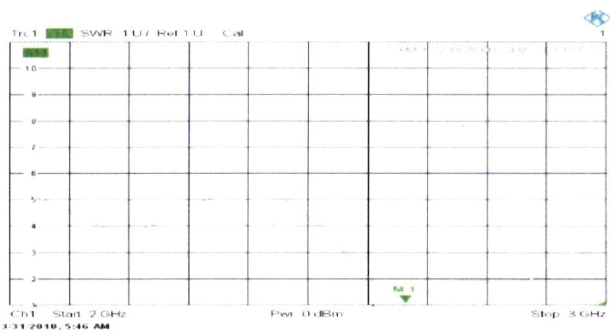

Fig. 10: VSWR of measurement result

Fig. 11 is the simulated radiation pattern of single patch antenna with directivity of 5.898 dB and gain of 0.837. Fig. 12 is the simulated radiation pattern of patch array antenna with directivity and gain of 10.25 dB and 5.732 dB respectively. As both radiation patterns compared, it can be concluded that the array design antenna generates more intensity or focus at the center of the radiation. This comparison is parallel to the theory that the array antenna itself is used to increase the directivity of antenna besides used to increase the bandwidth.

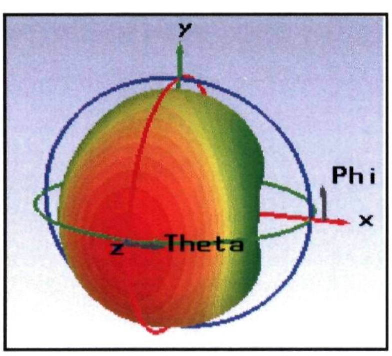

Fig. 11: The radiation pattern of single antenna

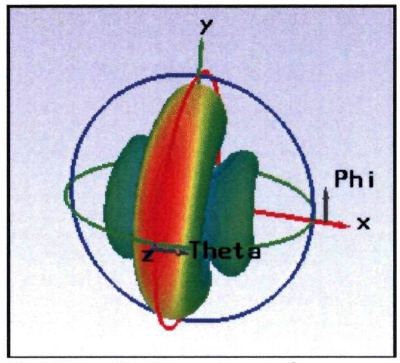

Fig. 12: The radiation pattern of array antenna

Fig.13 and 14 show the radiation pattern for simulation and measurement of patch array antenna. The simulation result shows the major lobe directed the signal at 0° with beamwidth (HPBW) of 24.7 °. The measurement result shows the major lobe is shifted few angle to the left of centre angle 0° at 353° with beamwidth (HPBW) of 33.9 °. This is possibly because of the noise floor from the equipment itself and also the measurement is done in open space where this should be done in the chamber to reduce the effect of noise.

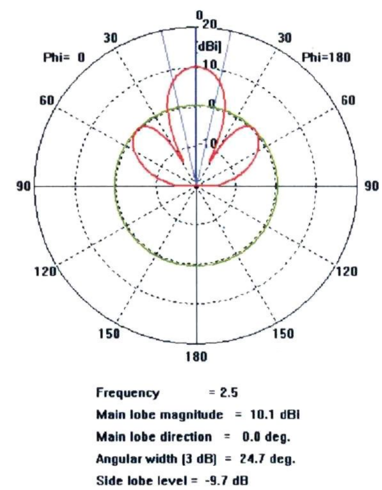

Fig. 13: The simulated radiation pattern of array antenna

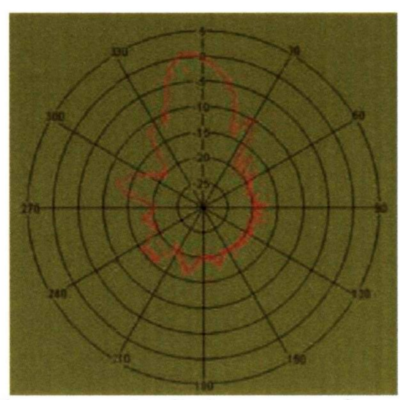
Fig. 14: The measured radiation pattern of array antenna

VI. CONCLUSSION

A microstrip rectangular patch array antenna that feed by microstrip line has been designed, simulated, fabricated, measured and analyzed. Overall, the performance of the antenna meets the desired requirement in term of return loss and VSWR. The simulation return loss is equal to -20.24 dB and VSWR is 1.215 at the centre frequency of 2.5GHz. However, in measurement, the centre frequency has been shifted about 6.8% from its original state. The performances of the microstrip antenna strongly depend on several factors such as type of substrate, the thickness and dielectric constant of substrate respectively. One of the ways of increasing the performances of the antenna is by doing an array configuration instead of use single element of the antenna. The way antenna has been fed is also important where the matching technique contribute to a massive impact to the performances of antenna.

VII. FUTURE RECOMMENDATIONS

In future, the microstrip rectangular antenna can be upgraded. The substrate FR4 used in this project can be replaced by another substrate such as RT Duroid 5780 which has low loss tangent, thus increasing the efficiency of the antenna. In term of configuration, the total size of antenna can be reduced by changing the feeding technique. Instead of using microstrip line, the inset feed technique can also be used.

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