Single Microstrip Patch Antenna with Aperture Coupler Fed Technique at 2.4GHz

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Abstract — **This paper presents the basic design of the single microstrip rectangular patch antenna with aperture coupler fed technique which operates at 2.4GHz frequency. The microstrip rectangular patch antenna with aperture coupler feeding was designed and simulated using CST Microwave Environment software 2009 (Computer Simulation Technology 2009) and to be used for wireless application. The basic designation is the aperture coupled microstrip antenna couples the patch antenna with microstripline through an aperture. The performance results of the designed and simulation antenna was analyzed in terms of return loss (S11) in dB, VSWR, radiation pattern and gain. The most effective way to increase the return loss is to optimize the patch shape, feed shape and slot shape. With chosen suitable combination substrate and perfect match between them, it will give an optimum and the best improvement of the radiation pattern.**

Keywords- **Aperture Coupled Antenna, Microstrip Antennas, Microstrip Line Feeding, substrate FR-4.**

I. INTRODUCTION

Recently in last few years when modern wireless communication systems are spreading fast, growth and develops rapidly, a basic antenna which is considered as the most important component that for transmitting and receiving signal process is required to have a good performance in all basic specification requirements. One of types of wireless communication at 2.4 GHz is Wireless Fidelity (WiFi) [1]. A WiFi enabled device such as a personal computer, video game console, smartphone or digital audio player can connect to the Internet when within range of a wireless network connected to the Internet [2].

Basic antennas that are widely used in wireless application for now should be small in size, light in weight, little in volume and good in basic performance [3]. Therefore, to meet most of these requirements, rectangular microstrip patch antenna is the best choice to be preferred because of the meet of the basic requirement and additional of the easy compact structure and simple manufacturability. Microstrip patch antenna also flexible which means suitable to planar and non planar surfaces for many applications. Microstrip patch antenna can be fed by a few of methods and these methods can be categorized into two main categories which are contacting and non contacting methods. Contacting method means the feeder are grounded directed to the ground and the non contacting method means the aperture coupling is an indirect or non contacting method of feeding the resonant patch. This means the energy along the strip line radiated is coupled through the slot in the ground plane and excites through the patch. This aperture or named slot is usually centered with respect to the patch has its maximum magnetic field. This antenna is a multilayer antenna which starts with a patch on the top of the first substrate. The first substrate is the one sided and the second substrate is double sided. Both substrate been used is FR-4. The main reason an aperture coupled been designed for the microstrip slot antenna is to improve its radiation pattern. This requirement can be fulfilled by a new aperture coupled microstrip antenna which was introduced by D.M Pozar in the year 1985 for the first time.

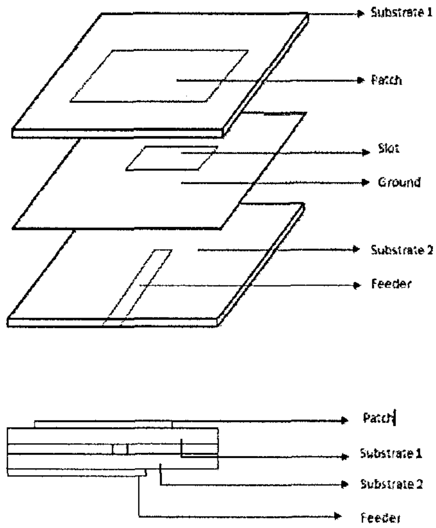

Figure 1: Aperture Coupled Microstrip Antenna

Figure 1 above shows the basic geometry of the aperture coupled rectangular microstrip patch antenna. The antenna mainly consist two substrates which are FR-4. The first substrate which is the first layer is single sided and the second layer is the double sided substrate. It starts with the patch on the top followed by first substrate for the first layer. The second substrate is ground on the top and feeder at the back. They are bonded drilled together with a ground plane in between. After combination the antenna will become a multilayered antenna and both the radiating patch on the top antenna substrate 1 (FR-4) while the microstrip feeder line on the bottom substrate 2 (FR-4). In between of them at the ground plane, there is a slot which is a small non-resonant aperture that couples the patch to the feed line. Aperture coupled microstrip antenna has many advantages. Some of them are such as used in the monolithic phase array with no radiation from the feed network can interfere with the main radiation pattern. Other advantages are also no need to make a direct connection to the antenna elements, so it eliminates the soldering process and because of its configuration which is the rectangular coordinate system is the most convenient system to express the field at the aperture and to perform the integration [4].

II. METHODOLOGY

Fig. 2 below shows the flowchart of the antenna design process. It starts with the collection and research of the information of aperture coupled microstrip patch antenna and further some literature review was done. Next step the antenna was design on CST Microwave Environment 2009 based on basic formula and equation for microstrip patch antenna in order to obtain the simulation results. For better result, the optimization process were done. The main objective in optimization process is to separate the design and calculation theoretically parameters which are always constant during the optimization from the design variables that are going to be changed and varies. This process will continue until get the best result and meets the objective. This process also passes through the try and error process. The result will be analyzed based on the best optimization result that is obtained.

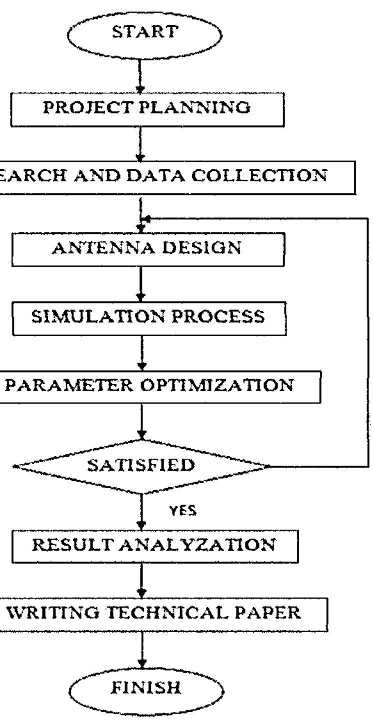

Figure 2: Flowchart of antenna design

III. ANTENNA DESIGN

In designing a microstrip patch antenna, it is important to choose a suitable dielectric substrate with appropriate thickness and loss tangent, so the best choice is RT Duroid 5870. RT Duroid 5870 is the best substrate because it meets the specification which is low in loss tangent that will not affect or reduce the antenna efficiency. It also has a relatively low dielectric constant. Unfortunately, while considering in term of cost, the cost of using RT Duroid 5870 for designing antenna is too much expensive compare to FR-4. FR-4 is much less cost and it is already supplied in the lab. There are also numerous substrates that can be used for the design of microstrip antenna and their dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$, but in this design the best choice is FR-4[5]. FR-4 in comparison has a higher dielectric constant which results in a smaller patch size but the high tangent loss will result in lower gain. In this paper, the antenna design uses the FR-4 as the substrate with thickness of 1.6 mm, copper as the ground, patch and feeder. The slot is on the ground plane with thickness of 0.035 mm. The proposed design of single patch microstrip antenna with aperture coupler fed follows specifications as summarized in Table 1 below.

TABLE I
DESIGN SPECIFICATION FOR MICROSTRIP PATCH ANTENNA

Center Frequency,fo	2.4 GHz
Substrate	FR-4
Dielectric Constant	5.0
Substrate Height	1.6mm
Copper Thickness	0.035 mm

A. Microstrip Patch Antenna Design

In this design the shape that been choose is rectangular patch antenna because it is very easy to design and analyze using transmission line. This shape also cavity models which most accurate for thin substrates and easy to fabricate. The shape of the patch is the main parameter which affects its electrical characteristics such as polarization and gain. The shapes of patch antenna could be several of shape such as square, rectangular, circular, triangular, thin strip or any other configuration. The design of microstrip rectangular patch antenna is beginning by determine its patch dimension by using the basic equation and formula. The width and length equation of the patch are given as follows:

The width of the patch:

$$\mathbf{W} = \frac{c}{2fo\sqrt{(\varepsilon r+1)/2}} \quad (1)$$

Where $c = 3\text{x } 10^{-8}$

The patch length:

$$L = L_{eff} - 2\Delta L \quad (2)$$

Where

$$L_{eff} = \frac{c}{2fo\sqrt{\varepsilon e}} \quad (3)$$

$$\varepsilon_e = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+12h/W}} \quad (4)$$

$$\Delta L = 0.412h\,\frac{(\varepsilon_e+0.300)(\frac{W}{h}+0.264)}{(\varepsilon_e-0.258)(\frac{W}{h}+0.800)} \quad (5)$$

ΔL is the gap between substrate and patch antenna.

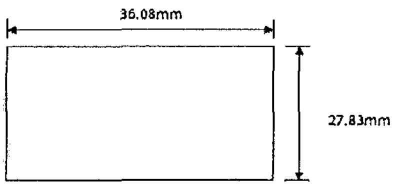

Figure 3: Structure diagram of the patch antenna

From the calculation to obtain the width and length by using equation (1) to (5) respectively, the width and length of patch antenna are 36 mm and 27 mm as shown in Figure 3 above. The dimension of the patch antenna is vary depends on the operating frequency and dielectric substrate.

B. Ground Plane Design

The ground plane dimensions can be obtained by using the below equations:

The width of the ground:

$$W_g = 6h + W \quad (6)$$

where W is the width of the patch antenna
The length of the ground:

$$L_g = 6h + L \quad (7)$$

where L is the length of the patch antenna

By using equation (6) to (7) the width and length ground plane in this design is 46.044 mm and 37.59 mm respectively. The dimension is shown in figure 4 below

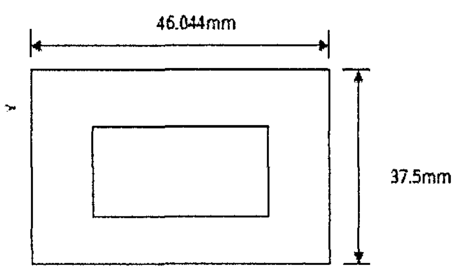

Figure 4: Structure diagram of the ground antenna

C. Microstrip Feedline Design

Next is to determine the width and length of microstrip feedline by using given equation as below:

For $W/_d < 2$;

$$W/_d = \frac{8e^A}{e^{2A}-2} \quad (8)$$

For $W/_d > 2$;

$$W/_d = \frac{2}{\pi}\left[B-1-\ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] \quad (9)$$

where

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

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

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

From the calculation using equation (8) to (12), the width and length of microstrip feedline is 2.78 mm and 16.08 mm respectively.

D. Coupling Aperture

The shape of the coupling aperture has a significant impact on the strength of coupling between the feed line and patch [6]. The slot or aperture can be in different shapes and size as shown in Figure 4 below.

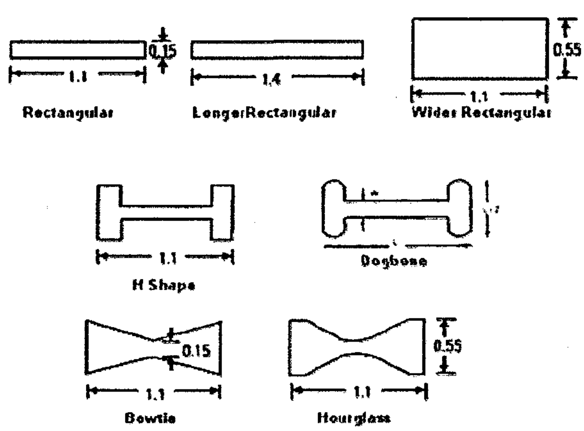

Figure 5: Different shapes of slot

The ratio of the slot length to its width is typically 1:10. Smaller aperture areas will result in lower back radiation levels, leading to less spurious radiation in the back region and improve efficiency [7]. Besides that, shape of the patch antenna also influences the performance of the antenna. One of the factors is also the shape of slot that can affect the performance of the antenna. In terms of feeding technique, rectangular shape was chosen in this design simulation. The use of rectangular slot in this antenna will improve the coupling for a given aperture area due to its increasing magnetic polarizability [8]. The length and width of the slot is 11.6 mm and 2.9 mm respectively.

E. CST Simulations

Computer Simulation Technology (CST) Microwave Environment 2009 was used to perform the design and simulate process in order to obtain the results. However, the actual value parameters from the theoretical formula and equation will not be the same in simulation parameters value. There will be different and it will be necessary to vary the value of the patch width, length and other parameters such as length and width of microstrip line of 50 Ω impedance in order to optimize the performance of antenna. Table 2 below shows some variation parameters and comparisons between theoretical calculation and simulation that were made in order to choose the best and final design.

From the Table II below it can see that the length and width of the patch antenna by using the basic equation and calculation gives the poor result. This happens because of the small and fit grounded. The slot also should be wider. For maximum coupling, the patch should be centered over the slot but in this paper the slot is not centered with the patch. A small rectangular aperture gives much stronger coupling. The best result for this design is when the patch width and length size 50 mm and 24.5 respectively. The result more stable and good after the width of the grounded was increased.

TABLE II
DESIGN SPECIFICATIONS

Dimension		Calculation	Adjustment Value		
Patch Width (mm)		36	40	45	50
Patch Length (mm)		27	25	25	24.5
Slot	*Width (mm)*	13	11.6	11.6	11.6
	Length (mm)	1.3	1.1	1.1	2.9
Feeder	*Width (mm)*	2.78	3	3	3.5
	Length (mm)	16	20	25	30
S11 dB		-0.39	-1.00	-2.00	-20.77
VSWR dB		43.62	17.34	6.99	1.20
Gain		-1.97	0.62	2.23	4.010

IV. RESULTS AND DISCUSSIONS

Figure 5 shows the graph result of return loss (S11) for simulation and measurement. The simulation graph drop at the accurate operating frequency 2.4 GHz but the measurement result it shifts to the 2.7 GHz. With perfectly tuned, the antenna is accurate at frequency operating, 2.4 GHz which one of the factor that influence the operating frequency is the stub length or the position of the slot or aperture. It gives the greatest effect on the operating frequency. The graph also changes into better figure when the cable of the VNA machine is moved. This means there is also a loss in term of equipment error and the fabrication. There is occurring an air gap while measure process between the aperture and the second substrate that effect the best result.

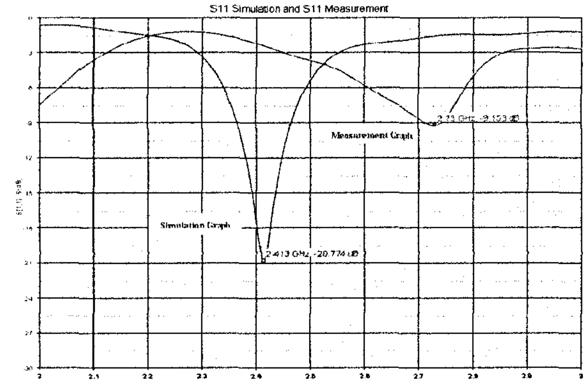

Figure 5: Return loss result simulation and measurement

Figure 6 below shows the return loss (S11) of the simulation result of aperture coupled microstrip patch antenna that been design in dB. S11 represents that how much power is reflected back from the antenna while radiating. If S11 is equal to 0 dB, that means all of the power is reflected from the antenna and nothing is radiated back. If S11 is equal to 20dB so this tells that if 3 dB of power is delivered to the antenna and the balance that is -17 dB is the balance power or the reflected power. The simulation result gives a return loss of -20.774360 dB at operating frequency 2.4 GHz which is the best result after doing some optimization and verification parameters. It shows that if S11 is less than -10dB, the more power is delivered to the antenna. That is inversely proportional between them. Larger return loss indicates higher power being radiated by the antenna which eventually increases the gain. In other word, the increase in S11 shows that the antenna has a better reflection coefficient and power reaches the load with minimal losses [9].

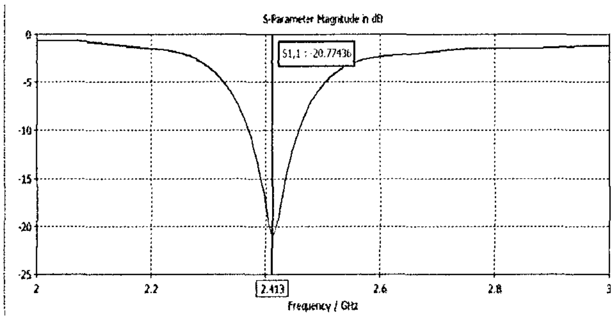

Figure 6: Return loss of simulation result

Basically the numerical value of VSWR ranges from a value of 1 to an infinite value for theoretically. It makes complete the reflection. Voltage Standing Wave Ratio, VSWR is the ratio of maximum to minimum amplitude of the corresponding field components appearing on a line that feeds an antenna. Figure 7 is the simulation result of voltage standing wave ratio VSWR at centre frequency 2.4 GHz the VSWR value is 1.20. Since there is always a small loss on a line fabrication hardware, the minimum voltages is never zero and the VSWR is always some finite value. On simulation the graph drops at the exact value of the operating frequency which is 2.4 GHz.

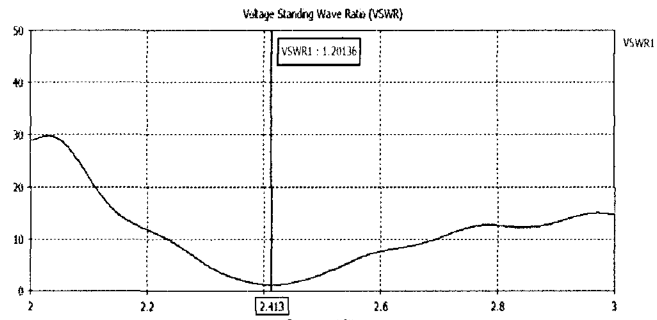

Figure 7: VSWR of simulation result

The directivity or directive gain of an antenna is a measure of the concentration of the radiated power in a particular direction. Figure 8 and Figure 9 above show the simulated radiation pattern of patch antenna. It shows with gain of 4.01dB. The higher gain will show the thick red in colour and better gain of the antenna. The simulation result shows the major lobe directed the signal at 0° with beamwidth (HPBW) of 98.4 °. Front to back ratio is the different in dB between the level of the maximum radiation in the forward direction and the level of radiation at 180°. The front to back ratio (F/B) is 7.1dB. Gain is another measure to describe the performance of an antenna [10].

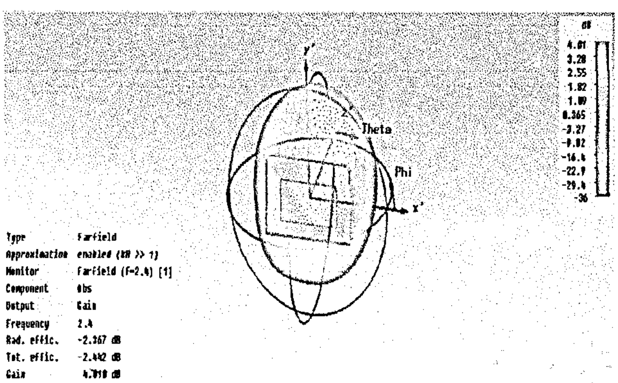

Figure 8: The radiation pattern of antenna

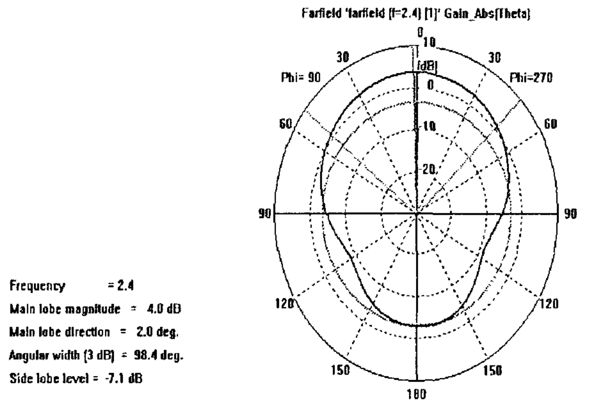

Figure 9: The simulated radiation pattern

V. CONCLUSION

A microstrip patch antenna that fed by microstrip line by using aperture coupler technique has been successful design, simulated and fabricated in range period that been given. The simulation return loss is equal to -20.77 dB and VSWR is 1.20136 at the centre frequency of 2.4 GHz but while compare to the measurement result is -9 dB and drop at 2.7GHz. This could happen because of the equipment error and the fabrication not perfect. The air gap and the not suitable substrate that is high in dielectric constant been chose. The performances of the aperture coupler antenna almost strongly depend on several factors such as type of substrate, the thickness, dielectric constant of substrate and stub length related to position of the slot or aperture. The way antenna has been fed is also important where the matching technique contribute to a massive impact to the performances of antenna and parameters results.

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