DESIGN OF APERTURE COUPLED MICROSTRIP ANTENNA AT 2.5 GHz

Norhidayu Binti Mohd Zin

Faculty of Electrical Engineering, Universiti Teknologi MARA Malaysia,
Shah Alam, SELANGOR

Abstract– Aperture coupling is indirect method of feeding the resonant patch. An aperture coupled microstrip antenna consists of two substrates separated by a ground plane and a small aperture is cut in the ground plane. An aperture coupled patch antenna at 2.5 GHz frequency is proposed in this paper. Besides, the desired value of return loss and *VSWR* can obtained before starting design another patch at 3.5 GHz and 4.5 GHz. There are three important design element involved in this antenna design, specification of the frequency resonant, material of dielectric constant and thickness to be used, patch dimension calculation, length and width of feed line and aperture coupling size before modeling and simulation using *CST* Microwave Studio 2006. The return loss, *VSWR* and farfield response as the simulation results would be shown in the form of graphs.

Keyword(s): Radio frequency (*rf*), aperture coupled microstrip antenna, return loss, Voltage Standing Wave Ratio (*VSWR*), Computer Simulation Technology (*CST*)

1.0 INTRODUCTION

Microstrip antennas have attracted much attention from researchers and engineers and have been used extensively in *rf* and microwave systems, such as communications, radar, navigation, remote sensing, and biomedical systems. Microstrip antennas can be in various forms, such as patch, dipole, slot, or traveling-wave structure, which designed for specific application but share the common features of a thin flat metallic region called patch, dielectric substrate, a ground plane (usually larger than the patch) and a feed which supplies *rf* power [1].

The four most popular feeding methods of microstrip antennas are microstrip line, coaxial probe, aperture coupling, and proximity coupling. The various configurations of elements possible choice of feeding method depends on the bandwidth, polarization, efficiency, the pattern shape and scan coverage [2].

Since the aperture coupled microstrip antennas was introduce in 1985, the features offered by this antenna element have been proved to be useful in a wide variety of applications, and the versatility and flexibility of the basic design have led to an extensive amount of development and design variations throughout the world [4].

2.0 THEORY

The aperture coupled microstrip antenna is the field coupled from the microstrip line feed to the radiating patch through an electrically small aperture or slot cut in the ground plane. The aperture is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The shape, size, and location of the aperture decide the amount of coupling from the feed line to the patch. The slot can be either resonant or no resonant. The resonant slot provides another resonance in addition to the patch resonance thereby increasing the bandwidth at the expense of an increase in back radiation. As a result, a no resonant aperture is normally used. The performance is relatively insensitive to small errors in the alignment of the different layers. Similar to the electromagnetic coupling method, the substrate parameters of the two layers can be chosen separately for optimum antenna performance.

Aperture coupled feed behavior are difficult to fabricate, narrow bandwidth, easy to model, moderate spurious two substrates separated by ground plane, feed at bottom substrate, patch on top and the energy coupled to the patch via a slot on ground plane. The aperture coupled feed used the bottom substrate high ε_r and top substrate with low ε_r [2].

The aperture coupled microstrip antenna has several advantages such as the top patch could be fabricated bandwidth and the feed network on the other side of the ground plane should be on a thin high dielectric substrate to reduce radiation losses.

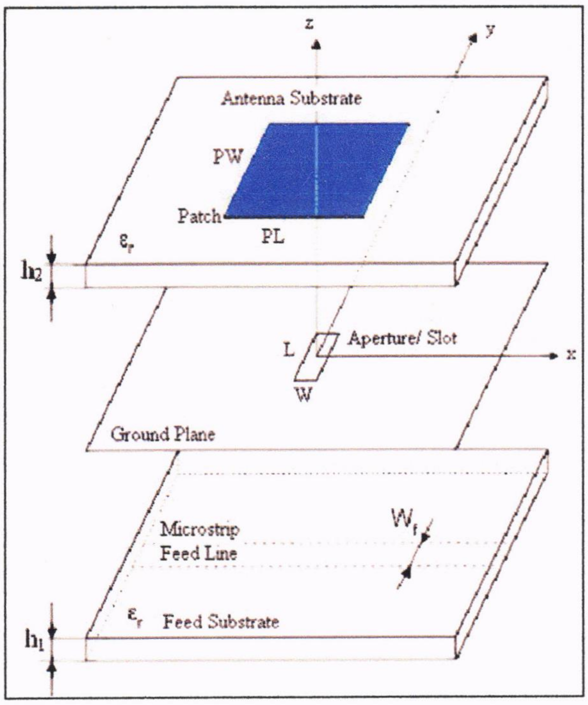


Figure 2.1: The Aperture-Coupled Microstrip Antenna

Besides, the radiation from the feed network does not interfere with the main radiation pattern, since the ground plane separates the two substrates. The excess reactance of the antenna also can be compensated by varying the length of the open-circuited microstrip stub and the input impedance is easily controlled by the size, shape and position of the aperture [5].

3.0 METHODOLOGY

3.1 Element Design

There are three important design element involved in this antenna design, specification of the frequency resonant, material of dielectric constant and thickness to be used, calculating the approximate patch dimension, length and width of feed line and aperture coupling before simulating using *CST* Studio Suite 2006B Computer-Aided Drawing (*CAD*) [6].

The most sensitive parameter in the estimation of antenna performance is the dielectric constant of the substrate material. Small variations in the substrate dielectric constant or dimensional changes due to temperature fluctuations can affect in frequency shift. Therefore substrates used in the design of microstrip antennas need to be a high quality in terms of stability in their mechanical and electrical properties. The materials with lower dielectric constant will provide greater bandwidth, more directive and more efficient antennas. However, with thinner substrates, the bandwidth will be small.

The radiating microstrip patch element is etched on the top of the antenna substrate, and the microstrip feed line is etched on the bottom of the feed substrate. The thickness and dielectric constant of these two substrates may thus be chosen independently to optimize the distinct electrical functions of radiation and circuitry.

RT Duroid 5880 substrate with permittivity $\varepsilon_r = 2.22$ and thickness h = 1.5875mm were preferred as the patch substrate, while Gallium Arsenide (GaAs), permittivity $\varepsilon_r = 12.9$ and thickness h = 0.1mm used for the feed substrate and for the microstrip feed line, ground and patch antenna, a perfect electrically conducting (PEC) was chosen.

3.2 Patch Size Calculation

Firstly, the patch antenna width, w can be calculated using the following equation [3]:

$$w = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

where c is the speed of light at $3\times10^8\ \mathrm{m\ s^{-1}}$, while the permittivity of the patch substrate, ε_r is 2.2.

Secondly, the effective permittivity, ε_{reff} is calculated using equation (2):

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\sqrt{1 + 12\frac{h}{w}} \tag{2}$$

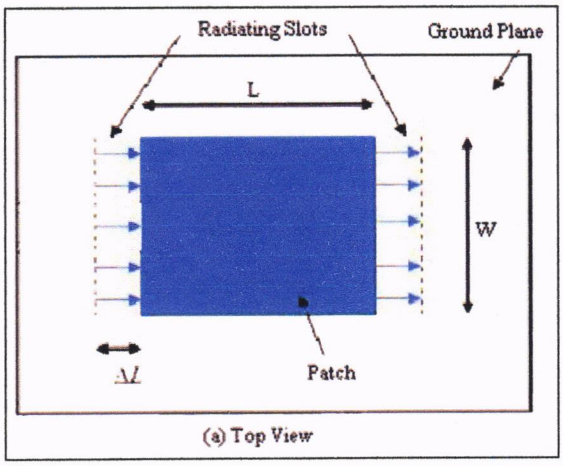
where the value of the substrate thickness, h, is obtained from a data sheet of microstrip laminates.

Then, the effective length, L_{eff} can be calculated using equation below:

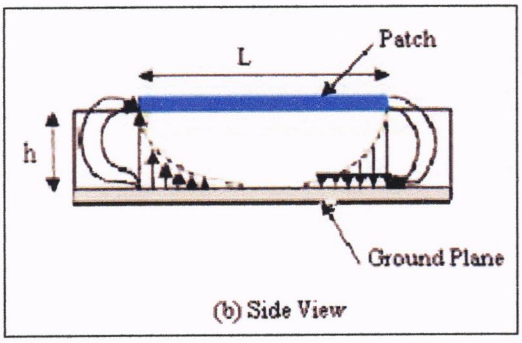
$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{3}$$

After that, the length extension, ΔL can be calculated using:

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \tag{4}$$



(a) Top View



(b) Side View

Figure 3.1: The Basic Structure the Patch of Microstrip Antenna

The length of patch can be calculated using formulae:

$$L = L_{eff} - 2\Delta L \tag{5}$$

The ground extension, L_g and W_g can be calculated using:

$$\begin{aligned} L_g &= 6h + L \\ W_g &= 6h + W \end{aligned} \tag{6}$$

The length and width of the feedline for the patch antenna for 50Ω impedance matching network was taken straightly from Eesof Libra by using Linecalc.

After all the desired value was obtained, the next step is to create the required patch antenna using all the previous values by using *CST* Microwave Studio 2006.

4.0 RESULT AND DISCUSSION

The entire figures and tables below show the results that obtained from *CST* Microwave Studio 2006 software after doing the simulation at 2.5 GHz. Simulations are done by changing the patches width and length, aperture coupling and feed line size. From the analysis, the aperture coupling and feed line size are kept varied until the desired responses are achieved.

Table 1: The Structural Details of Aperture Coupled Microstrip Antenna at Different Frequencies

Antenna	**Dimension/ Parameter at Different Frequencies**		
Element	**2.5 GHz**	**3.5 GHz**	**4.5 GHz**
Patch	$l = 44$ mm $w = 37$ mm $t = 0.1$ mm PEC	$l = 32$ mm $w = 27$ mm $t = 0.1$ mm PEC	$l = 26$ mm $w = 20$ mm $t = 0.1$ mm PEC
Patch Substrate	$l = 43.29$ mm $w = 50.43$ mm $h_2 = 1.5875$ mm RT Duroid 5880 $\varepsilon_r = 2.2$	$l = 30.319$ mm $w = 36.214$ mm $h_2 = 1.5875$ mm RT Duroid 5880 $\varepsilon_r = 2.2$	$l = 24.009$ mm $w = 28.833$ mm $h_2 = 1.5875$ mm RT Duroid 5880 $\varepsilon_r = 2.2$
Aperture coupling	$l = 11$ mm $w = 2.0$ mm $t_2 = 0.1$ mm Vacuum	$l = 8.2$ mm $w = 2.0$ mm $t_2 = 0.1$ mm Vacuum	$l = 6$ mm $w = 2.0$ mm $t_2 = 0.1$ mm Vacuum
Ground Plane	$l = 43.29$ mm $w = 50.43$ mm $t_2 = 0.1$ mm PEC	$l = 30.319$ mm $w = 36.214$ mm $t_2 = 0.1$ mm PEC	$l = 24.009$ mm $w = 28.833$ mm $t_2 = 0.1$ mm PEC
Feed substrate	$l = 43.29$ mm $w = 50.43$ mm $h_1 = 0.5$ mm Gallium Arsenide (GaAs) $\varepsilon_r = 12.9$	$l = 30.319$ mm $w = 36.214$ mm $h_1 = 0.5$ mm Gallium Arsenide (GaAs) $\varepsilon_r = 12.9$	$l = 24.009$ mm $w = 28.833$ mm $h_1 = 0.5$ mm Gallium Arsenide (GaAs) $\varepsilon_r = 12.9$
Feed line	$l = 22.646$ mm $w = 0.3$ mm $t_l = 0.05$ mm PEC	$l = 16.1595$ mm $w = 0.1$ mm $t_l = 0.05$ mm PEC	$l = 13.004$ mm $w = 0.18$ mm $t_l = 0.05$ mm PEC

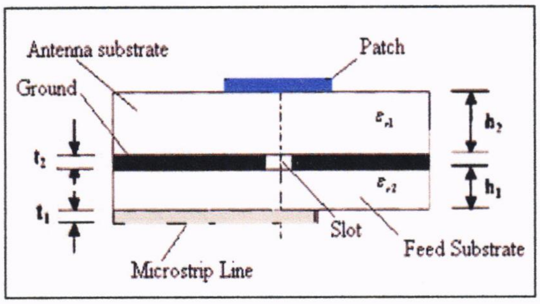


Figure 4.1: The Geometry of Aperture Coupled Microstrip Antenna Design

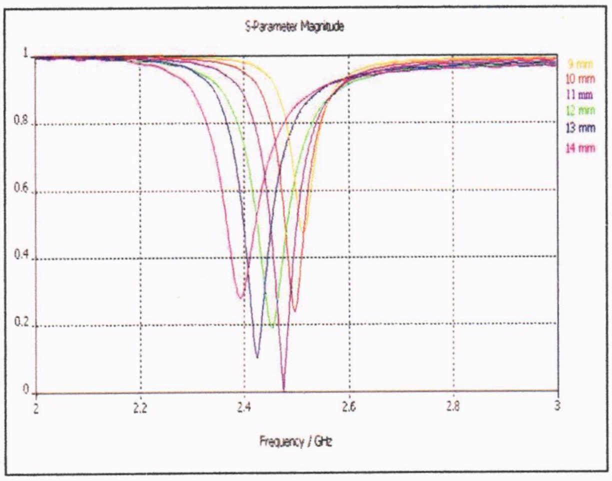


Figure 4.2: Return Loss (S_{11}) Magnitude versus Frequency for Different Aperture Coupling Length

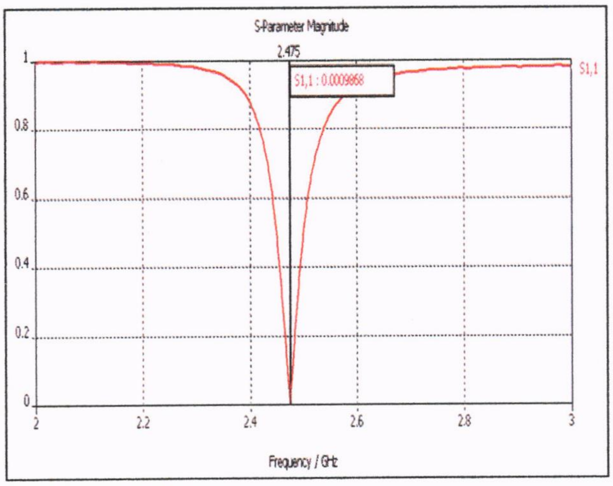


Figure 4.3: Return Loss for Aperture Coupling Length is 11 mm

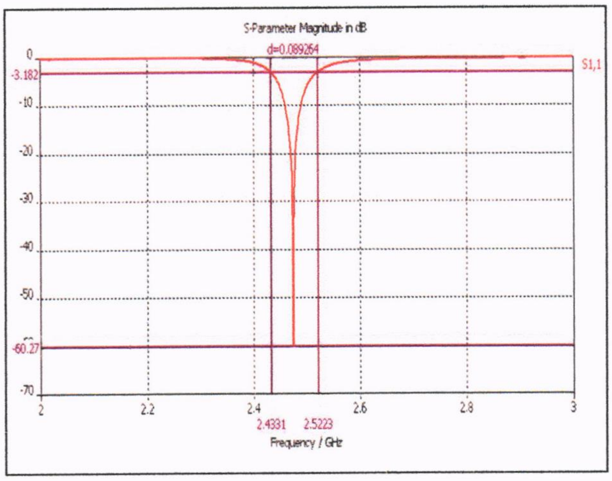


Figure 4.4: The Bandwidth from S_{11} (dB) Graph of Aperture Coupled Microstrip Antenna at 2.5 GHz

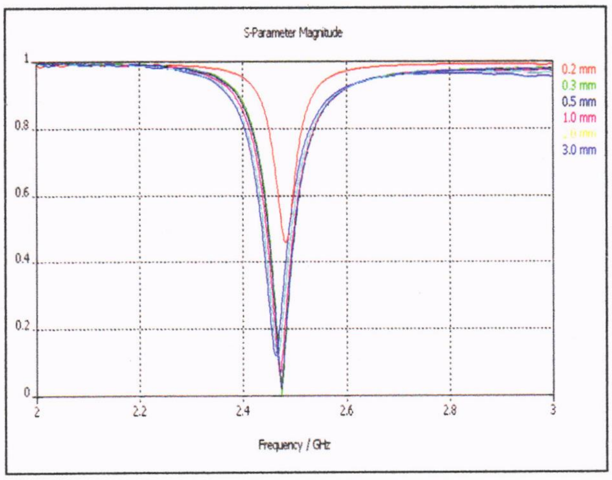


Figure 4.5: Return Loss (S_{11}) Magnitude versus Frequency for Different Feed Line Width

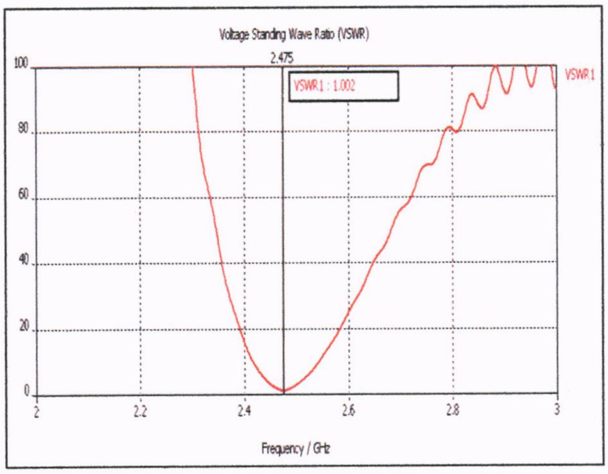


Figure 4.6: The *VSWR* Graph of Aperture Coupled Microstrip Antenna at 2.5 GHz

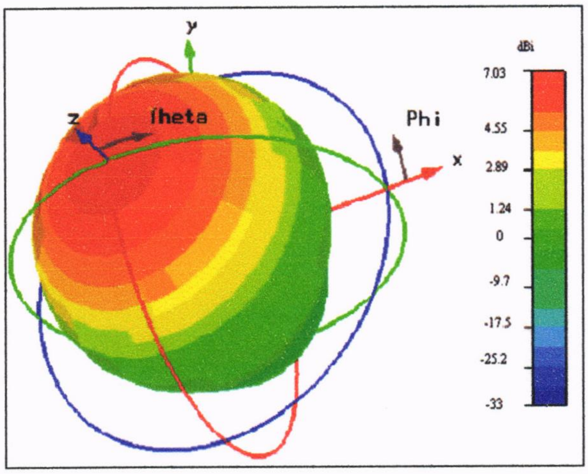


Figure 4.7: The Farfield Power Radiation at 2.5 GHz of Aperture Coupled Microstrip Antenna

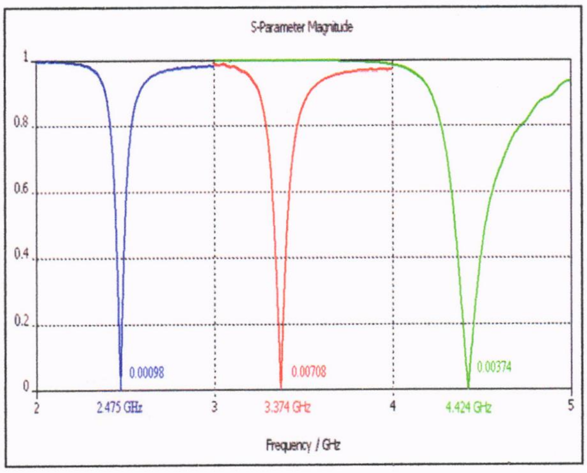


Figure 4.8: The Comparison of Return Loss (magnitude) at 2.5 GHz, 3.5 GHz and 4.5 GHz

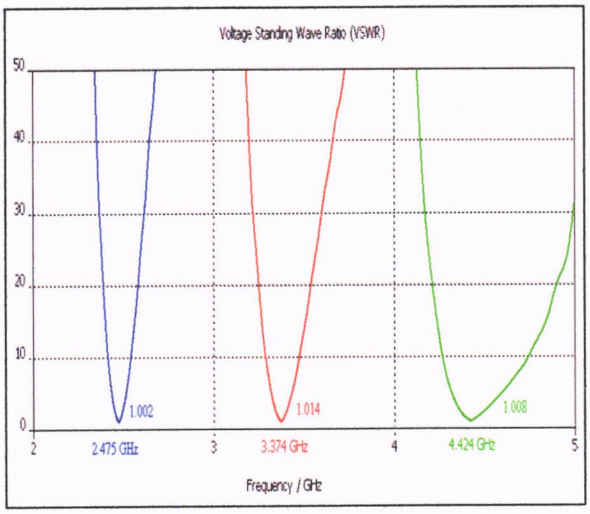


Figure 4.9: The Comparison of *VSWR* at 2.5 GHz, 3.5 GHz and 4.5 GHz

Table 2: The Value Obtained from Figure 4.8 and 4.9

Frequency (GHz)	S_{11} (magnitude)	S_{11} (dB)	*VSWR*	Bandwidth (%)
2.5	0.00098	-60.12	1.002	3.61
3.5	0.00708	-43	1.014	3.86
4.5	0.00374	-48.53	1.008	7.23

Figure 4.1 shows the geometry of aperture coupled microstrip antenna design and the design details physical element of the structure design as shown in the Table 1.

The results plots in Figure 4.2 are obtained after varying the aperture coupling length. The center frequency is selected as the one at which the return loss is minimum and the optimum aperture coupling length is 11 mm where a return loss of -60.12 dB is obtained. From the theory, minimum return loss must be less than -10 dB to make sure the transmit signal spread out overall [1]. Besides, a center frequency of 2.475 GHz (refer to Figure 4.3) is obtained which is very close to the desired design frequency of 2.5 GHz. The observation from the graph illustrates that, the aperture coupling length affects the center of frequency and decrease the value of return loss slightly. The bandwidth for this aperture coupling length is calculated to be 89.2 MHz or 3.61 percent as shown in Figure 4.4.

Furthermore, the feed line width also manipulates the response of the antenna. The results plot in Figure 4.5 obtained after varying the feed line width from 0.2 mm to 3.0 mm. From the graph, the width of a feed line affects the value of return loss $S_{11.}$ The center frequency is selected as the one at which the return loss is minimum. The optimum feed line width is 0.3 mm where a return loss of -60.12 dB also obtained same as aperture coupling length.

Figure 4.6 present the value of *VSWR* at center of frequency, 2.475 GHz is 1.002. The expected value of *VSWR* must be less than 2 in order to minimize the power reflected of the transmit signal. *VSWR* indicates the ratio between the maximum voltages to the minimum voltage of the standing wave. This value shows that there is not much of the incident wave being reflected back from the patches.

The farfield power radiated in the positive z-direction proves that the antenna is transmitting a certain amount of current through its patch at the resonant frequency displayed in the Figure 4.7. Antenna is a device where it can either transmit or receive signals, and the farfield layout supports this fact. Red color indicates that the antenna radiate EM wave at maximum output, while blue color indicate that the EM field is weak. The colors are varies as it's indicate the different strength of the EM field. From that figure we can see that the antenna transmits a fully resonant frequency at 2.5 GHz, as the patches is radiating a fully EM field with the highest value of directivity (because the whole patches is completely red color in z-direction).

The comparison results of the aperture coupled microstrip antenna design as shown in Figure 4.8 and 4.9. This antenna operates at three different frequencies, 2.5GHz, 3.5GHz and 4.5 GHz, but after simulation the center frequency at 2.475 GHz, 3.374 GHz and 4.424 GHz were chosen because of the greatest expected response.

Figure 4.8 and 4.9 shows the combination of return loss and *VSWR* response at different frequencies. Blue marks graph shows the response at 2.5 GHz with center of frequency at 2.475 GHz, red marks graph shows the response at 3.5 GHz with center of frequency at 3.374 GHz and green marks graph illustrates the response at 4.5 GHz with center of frequency at 4.424 GHz. Summary of the value obtained at different frequencies as shown in Table 2.

From table 2, the higher percentage bandwidths achieved at 4.424 GHz frequency are about 320 MHz than 130 MHz at 3.374 GHz and 89.2 MHz at 2.5 GHz.

For those three different frequencies, the size of aperture coupling, feed line and dimension of patch decrease by the increasing frequency.

From optimization during the simulation process, the length of aperture coupling controls the value of return loss and the center of frequency. At 2.5 GHz frequency, the aperture coupling length weights the frequency resonant of the antenna as shown in Figure 4.2.

Moreover, the feed line width also controls the return loss response of the antenna design (refer Figure 4.5).

When the frequency was increasing, the dimension of the aperture coupled microstrip antenna decrease. To design at another frequency, the calculation of the patch size should be done at the desired frequency. Small patch dimension points were determined due to high frequency while bigger patch dimension position can be created at the lower frequency.

5.0 CONCLUSION

An aperture coupled microstrip antenna has been successfully designed and simulated. The purposed antenna is operates at 2.5 GHz and verification of the design at 3.5 GHz and 4.5 GHz. From the result and discussion, the value of S_{11} and *VSWR* were approximating to the expected value.

The simple analysis procedures offer an attractive design of aperture coupled microstrip antennas and has been designed by using *CST* Microwave Studio 2006 software to obtain the response at resonant frequency. There are three important condition involved in aperture coupled microstrip antenna design procedures, specification of the frequency resonant, substrate material properties, calculation of the patch dimension, model the antenna and simulation using *CST* Microwave Studio 2006 Software.

The dimension of the patch, aperture coupling and feed line manipulated the response of S-parameter return loss, VSWR and bandwidth of the antenna.

The greatest disadvantage of the microstrip antenna is its inherently low impedance bandwidth. But, this aperture coupled microstrip antenna achieved the bandwidth bigger than 3 percent. The higher percentage bandwidth achieved at 4.424 GHz frequency, about 320 MHz than 130 MHz at 3.374 GHz and 89.2 MHz at 2.5 GHz.

The problems faced during this design were the best value of S_{11} and *VSWR* cannot be achieved at desired frequency. Besides that, the bandwidth that obtained from the resonant frequency only achieves about 3 percent rather than the expected bandwidth of 10 percent. This is because the energy coupled to the patch via a slot on ground plane not radiated efficiently and the microstrip antenna performance is at narrow band.

6.0 FUTURE DEVELOPMENT

The useful feature of the aperture coupled microstrip antenna is that it can provide substantially improve impedance bandwidths to develop in commercial system. Today, the demand for microstrip antenna application so broad and has been increasing rapidly because of the typical maximum performance with little constraint on cost, commercial applications demand low cost components, often at the expense of reduced electrical performance.

For the future development, the bandwidth of an aperture couple microstrip antenna might be broad by trying to change the shape of the aperture coupling slot such as "H"-shape, "U"-shape, "L"-shape, bowtie or butterfly shape aperture.

CST Microwave Studio is a specialist tool for the fast and accurate 3D EM simulation of high frequency problems. Applications include the expanding areas from Mobile Communication, Wireless Design (Bluetooth), Signal Integrity and so on. Exceptionally user friendly, CST Microwave Studio quickly gave an insight into the EM behavior of high frequency designs.

Beside the flagship module, the broadly applicable Time Domain solver and the Frequency Domain solver which simulates on hexahedral as well as on tetrahedral grids, *CST* Microwave Studio offers further solver modules for specific applications. Filters for the import of specific CAD files and the extraction of spice parameters enhance design possibilities and save time. In addition, CST Microwave Studio is embedded in a larger design environment through *CST* Design Studio whose open architecture provides a link with external simulators.

7.0 ACKNOWLEDGEMENT

I would like to thank my final project supervisor Encik Ahmad Asari Sulaiman, Assoc. Prof. Dr. Zaiki Awang, Pn. Nur Atiqah Sia, my friends Syawal Hisyam, Hana Syakirah, Zahir, Lily, Irwan, Lia, and others that had give their supports and guidance towards the success of this project.

8.0 REFERENCES

[1] Zhi Ning Chen and Michael Y. W. Chia, *Broadband Planar Antennas: Design Application*, John Wiley & Sons, Ltd 2006.

[2] Assoc. Prof. Dr. Zaiki Awang, *Microstrip Antenna Notes*, Faculty of Electrical Engineering, Universiti Teknologi MARA, 2001.

[3] Assoc. Prof. Dr. Zaiki Awang, PhD, *Telecommunication Engineering Monograph: RF DESIGN*, Faculty of Electrical Engineering, Universiti Teknologi MARA, 2001.

[4] Professor David M. Pozar, "A Review of Aperture Coupled Microstrip Antennas: History, Operation, Development, and Applications", Electrical and Computer Engineering University of Massachusetts at Amherst, May 1996.

[5] Girish Kumar, K.P. Ray, *Broadband Microstrip Antennas*, Artech House, INC, 2003.

[6] Computer Simulation Technology (*CST*) Microwave Studio® 2006.

[7] Nobuhiro Kuga, "An Aperture Coupled Patch Antenna on Modified-Shape Ground Plane", Yokonama National University, June 2005.

[8] Yu Hang and Zhu Qi, "A New Method to Analyze Micromachining Aperture Coupled Microstrip Antennas", Dept. of EEIS, University of Science & Technology of China, 2002.

[9] Stephen D. Targonski and David M. Pozar, "Design of Wideband Circularly Polarized Aperture Coupled Microstrip Antennas", Fellow, IEEE, 1993.

[10] A.Abdel- Rahman, A. K. Verma, G. S. Kirov and A.S. Omar, "Aperture Coupled Microstrip Antenna With Quasiplanar Surface Mounted Horn", Chair of Microwave and Communication Engineering University of Magdeburg, Germany, 2003.

[11] K. Rambabu and J.Bornemann,"Analysis and Design of profiled Multiaperture Stripline to Microstrip Couplers", Development, and Applications", Department of Electrical and Computer Engineering University of Victoria, Dec 2003.