Design of a Rectangular Microstrip Patch Antenna at 2.4 GHz with Defected Ground Structure (DGS) Effects

Aslinda Binti Zamah Shari
Faculty of Electrical Engineering
Universiti Teknologi MARA
Shah Alam, Selangor, MALAYSIA
aslindaz@yahoo.com

Abstract — **This paper presents the study on the effects of Defected Ground Structure (DGS) on rectangular microstrip patch antenna. The antenna was designed using substrate type of FR-4 with dielectric constant of 4.7, thickness of 1.6 mm, and tangent loss of 0.019. The antenna with and without DGS was analysed to compare the antenna performance between the simulation and the measurement results. The proposed antenna was analysed and simulated at 2.4 GHz for Wireless Local Area Network (WLAN) application. The antenna designed with DGS was 60% more compact than the antenna without DGS. The Computer Simulation Technology (CST) software was used during the simulation result. It was found that by using the DGS method, the size of antenna was reduced.**

Keywords: Microstrip Antenna, Defected Ground Structure (DGS), CST

I. INTRODUCTION

In the new era of millennium, communication plays an important role in the worldwide society. The communication technologies are rapidly switching from wired to wireless. The wireless communication advancement of technology has had an enormous impact on the world. Antennas play a very important role in the field of wireless communications. We can say antennas are the backbone and almost everything in the wireless communication without which the world could have not reached at this age of technology. Microstrip patch antenna are widely used in modern communication system and instrument such as Wireless Local Area Neworks (WLAN) due to their advantage such as low profile, light weight, ease of fabrication, low production cost, and conveniently to be integrated with microwave integrated circuits [1]. However, for the lower frequency, the size of the conventional microstrip patch antenna is large. Some application of the microstrip patch antenna in communication system required smaller antenna size in order to meet the maniaturization requirements. In addition, microstrip patch antenna have narrow bandwidth and many approaches have been utilizedsed for extending bandwidth for practical applications. Besides, the return loss is high. The losses that are due to the surface waves excitation will cause decrease in the antenna efficiency, gain and the bandwidth because when surface waves occur, it can extract total available power for radiation to space wave.

Therefore, The Defected Ground Structure (DGS) is embendded in the microstrip antenne to overcome return loss and bandwidth. Moreover, the Defected Ground Structure is one of the unique techniques to reduce the antenna size for a particular frequency [2-5]. DGS are widely used in microwave devices to make the system compact and effective. DGS is a technique where the ground plane of a microstrip antenna is purposely customised by adding any shape of slot to enhance the performance of an antenna. A defect shape is added on the ground plane to disturb the shielded current distribution, depending on the shape and dimension of the defect [3]. The disturbance at the shielded current distribution influences the input impedance and the current flow of the antenna. The defect shape can also control the excitation and electromagnetic waves propagating through the substrate layer [2]. On the other hand, by implementing microstrip antenna with DGS, higher operating bandwidth [5-7] and lower return loss [2, 9] can be achieved. DGS is getting more and more popular in antenna design. Various slots of DGS antenna have been reported such as V-shaped [6], hexagonal [7], dumbbell [4,10], fractal [5], H-shaped [8], F-Shaped [11] and rectangular [9]. Furthermore, DGS can be used in several applications such as antenna size reduction [2-5], cross polarisation reduction [6], harmonic suppression [8,10], and mutual coupling reduction in antenna arrays [7].

The objective of this paper is to design a rectangular microstrip patch antenna with DGS to reduce the size of antenna that operates at 2.4 GHz for Wireless Local Area Network (WLAN) application.

II. ANALYTICAL ANALYSIS OF THE ANTENNA

The proposed antenna was designed without embedded DGS, as shown in Figure 1. This antenna was used as a reference for both antennas with DGS. The antenna was designed on a FR-4 substrate with a relative dielectric constant, $\varepsilon_r = 4.7$ and thickness, h = 1.6 mm. The impedance of the microstrip line of 50 Ω was used.

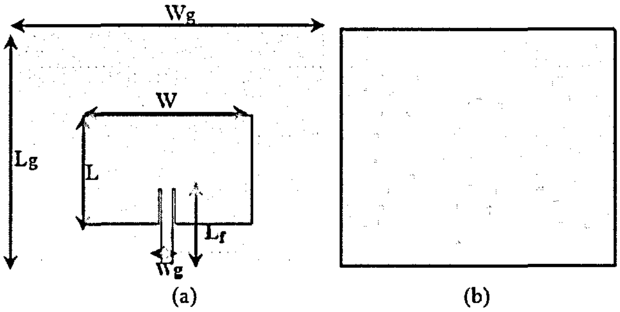


Figure 1 : Rectangular microstrip antenna design (a) Top view and (b) Bottom view

The formulas below were used to calculate the dimensions of rectangular microstrip patch antenna. The value of width and length was determined using Equation 1 and Equation 2, as shown below.

$$w = \frac{c}{2fr\sqrt{\frac{\varepsilon_r + 1}{2}}} \qquad (1)$$

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

$$L_{eff} = \frac{c}{2fo\sqrt{\varepsilon_{eff}}} \qquad (3)$$

where ε_{eff} and ΔL can be calculated by,

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w}\right)^{\frac{1}{2}} \qquad (4)$$

$$\frac{\Delta L}{h} = 0.412\left[\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right]\left[\frac{w/h + 0.264}{w/h + 0.813}\right] \qquad (5)$$

Equation 5 and Equation 6 show the microstrip feed line formulas.

$$\frac{w}{h} = \frac{8e^A}{e^{2A} - 2} \qquad for\ {}^{w}/_{h} < 2 \qquad (6)$$

$$l = \frac{{}^{90}/_{360} \times 2\pi}{k\sqrt{\varepsilon_{eff}}} \qquad (7)$$

A can be calculated by using Equation 8

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \qquad (8)$$

TABLE I. DIMENSION FOR RECTANGULAR MICROSTRIP ANTENNA DESIGN

	Frequency at 2.4 GHz	
	Calculated (mm)	Optimised (mm)
Width, W	37	44
Length, L	29	27.83
Width of the ground, W_g	74	80
Length of the ground, L_g	58	60
Width of the feedline, W_f	2.9	3.153
Length of the feedline, L_f	16	19

Then, the ground plane of the antenna was then purposely modified by adding a slot to observe the antenna performance. In this study, two types of antenna with DGS were considered, namely Aeroplane-shaped DGS and UiTM-shaped DGS. The geometry and shapes of the DGS slot are shown in Figure 2. Detailed dimensions are shown in Table II. Table (I) and (II) show that the size of the antenna with DGS is quite smaller compared to the antenna without DGS.

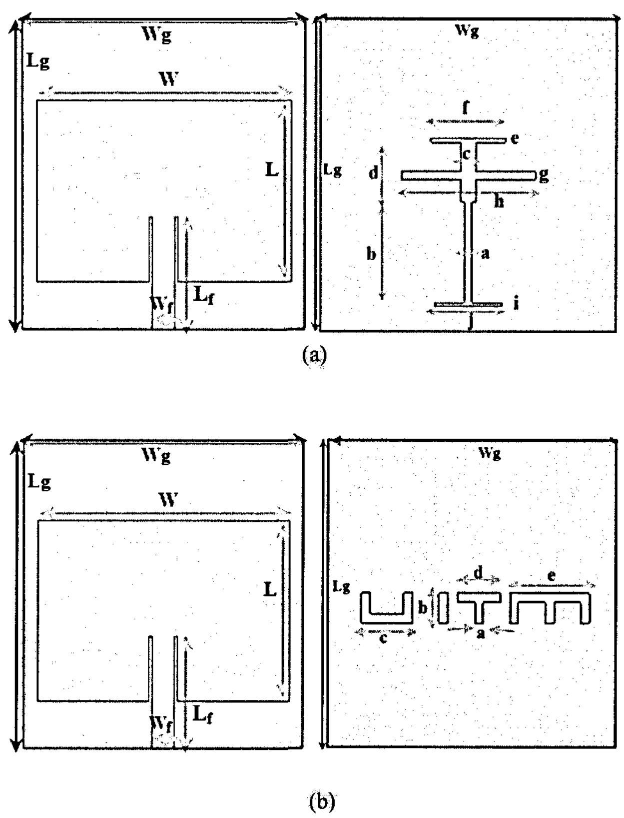


Figure 2 : Antenna geometry from top and bottow views. (a) Aeroplane-shaped DGS, and (b) UITM-shaped DGS

TABLE II. DIMENSION OF BOTH ANTENNAS

Parameter (mm)	Aeroplane-shaped DGS	UITM-shaped DGS
Length, L	24.82	24.2
Width, W	36	36
Length, L_g	42	42
Width, W_g	40	41
Width of the feedline, W_f	3.153	3.153
Length of the feedline, L_f	15.5	15.5
a	1	1.2
b	14	4
c	2	7.2
d	8	6
e	0.5	11.2
f	10	-
g	1	-
h	18	-
i	0.5	-
j	9	-

III. PARAMETRIC STUDY

The proposed DGS designed in this study was simulated by varying the dimension and locating the position of the DGS on the antenna without DGS. Figure 3 shows the effect of different dimension of the DGS. The effect can be seen by varying one dimension and by keeping the remaining ones constant in the same time. For the Aeroplane-shaped DGS, the dimensions of the parameter a, b, c, d, e, f, g, h, i, and j for the antenna structure were varied. However, in this paper only the antenna designed with varied parameter of *h* is shown, as depicted in Figure 3(a). The dimensions of parameter *h* were varied by keeping all other dimensions of parameter constant. The dimension of *h* was optimised from 12 mm to 18 mm with 2 mm increment. The result showed that with the increase in the dimension of *h*, the resonance frequency of the antenna decreased. This finding is also supported by other reseachers [10-11].

For the UITM-shaped DGS, two parameters were considered in this research, namely *a* and *b*. Both dimensions of the antenna parameter structure were varied. However, in this paper, only the antenna designed with varied parameter of *b* is shown, as depicted in Figure 3(b). The dimension of *a* was kept constant and the dimension of *b* was varied. The result showed that with the increase of dimension of the parameter *b* from 2.5 mm to 4 mm with 0.5 mm increment, the resonance frequency of the antenna decreased. Therefore, to maintain the resonance frequency at 2.4 GHz, the antenna size of antenna should be reduced.

The Effect of Different Dimension of the Structure

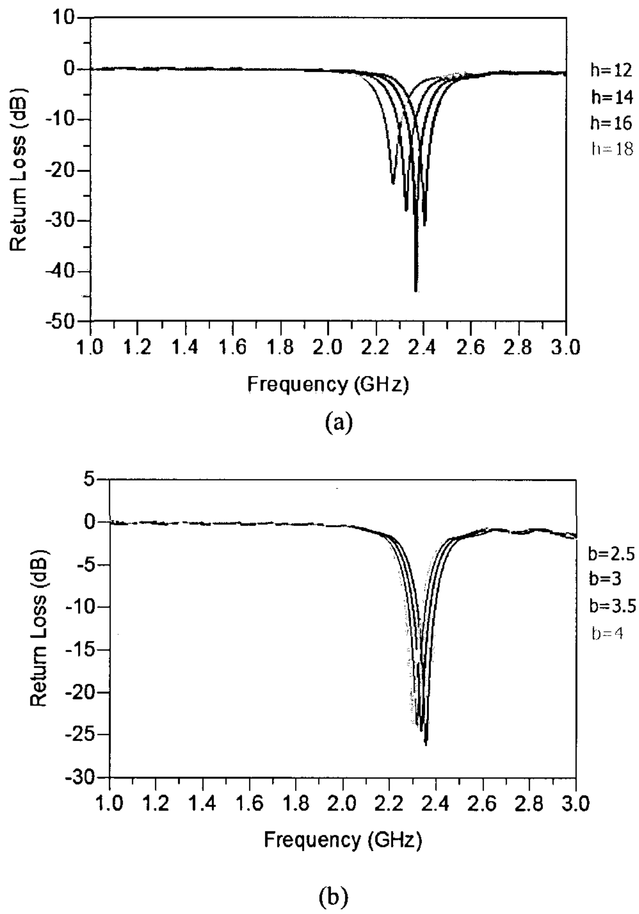


Figure 3 : Simulated S_{11} Parameter. (a) Aeroplane-shaped DGS and (b) UITM-shaped DGS

IV. SIMULATION AND EXPERIMENTAL RESULTS

Table III shows antenna parameter without DGS and Table IV shows antenna parameter with DGS. Both tables summarise the antenna parameters such as resonance frequency, bandwidth, return loss, gain, VSWR, and antenna size during the measurement and simulation process. The bandwidth in range of between 70 MHz to 104 MHz for both designs of the proposed antenna is improved. The gain for the proposed antenna was lower compared to the reference antenna. However, the gain value was considered high for the single antenna. Compared to the reference antenna, the Aeroplane-shaped DGS was more compact in size i.e., about 65%,.

Figure 4 shows the implemented prototype of the proposed antenna. Figure 4(a) shows the top view of the proposed antenna without DGS, while Figure 4 (b) and Figure 4 (c) show the bottom view of the proposed antenna with DGS.

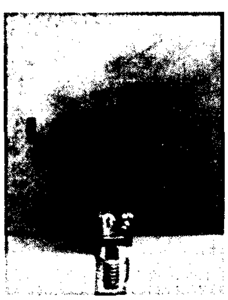
TABLE III. ANTENNA PARAMETERS WITHOUT DGS

Antenna Parameter	Simulation	Measurement
Resonance Frequency	2.4 GHz	2.51 GHz
Bandwidth	72 MHz	60 MHz
Return Loss	-23.88 dB	-20.79 dB
Gain	4.09 dB	-
VSWR	1.137	1.201
Antenna size	4800 mm^2	

TABLE IV. ANTENNA PARAMETERS WITH DGS

Antenna Parameter	Aeroplane-shaped DGS, Simulation	Aeroplane-shaped DGS, Measurement	UITM-shaped DGS, Simulation	UITM-shaped DGS, Measurement
Resonance Frequency	2.4 GHz	2.42 GHz	2.4 GHz	2.42 GHz
Bandwidth	104 MHz	96 MHz	96 MHz	70 MHz
Return Loss	-30.91 dB	-21.49 dB	-32.88 dB	-19.11 dB
Gain	3.24	-	3.46	-
VSWR	1.059	1.184	1.046	1.249
Antenna size	1680 mm^2 (65% Size Reduction)		1722 mm^2 (64% Size Reduction)	

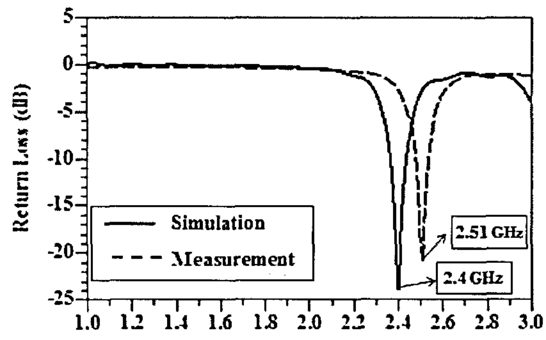
(a)



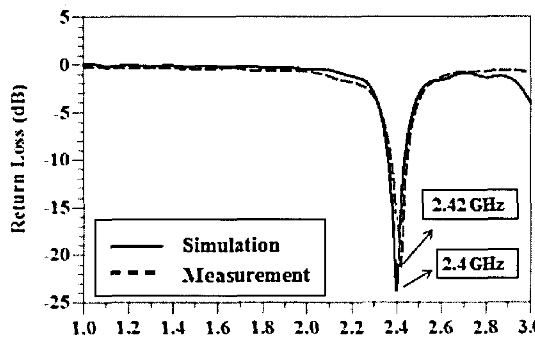
(b) (c)

Figure 4 : Fabricated Antennas: (a) Without DGS; (b) Aeroplane-shaped DGS; and (c) UITM-shaped DGS

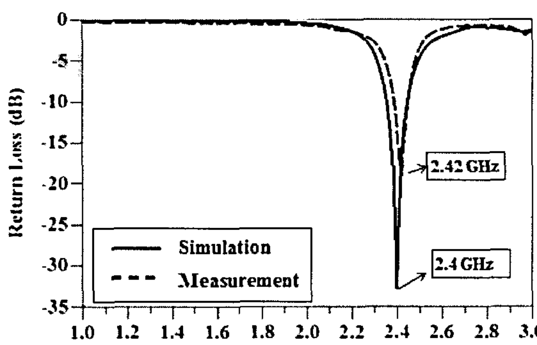
Figure 5 shows the S_{11} graphs of the simulation and the measurement results. The return loss for simulation result was much lower compared to the measurement result. However, the measurement result was under acceptable reflection coefficient S11 $\leq$ -10 dB. Figure 5(a) shows a slight shift of resonant frequency from simulation result compared to measurement result i.e., from 2.4 GHz to 2.51 GHz. Next, Figure 5(b) and Figure 5(c) show that the resonant frequency of prototype antenna was shifted about 20 MHz from the desired frequency i.e., 2.4 GHz. The resonant frequency shifted to the right from 2.4 GHz to 2.42 GHz. The shifted frequency was due to a little bit error on its dimension during the cutting process thus the error affected the antenna performance. However, it was found that the measurement result was in agreement with the simulation result.



(a)



(b)



(c)

Figure 5 : Simulation and Measurement Return Loss: (a)Without DGS; (b) Aeroplane-shaped DGS; and (c) UITM-shaped DGS

Figure 6 illustrates the radiation pattern in a polar E-plane during the simulation and measurement process with and without DGS.The result showed that the measurement result almost same with the simulation result. Measurements errors were mainly because the antenna measurements were not carried out inside an anechoic chamber. The measurement result was in good agreement with the simulation result and gave a good performances result.

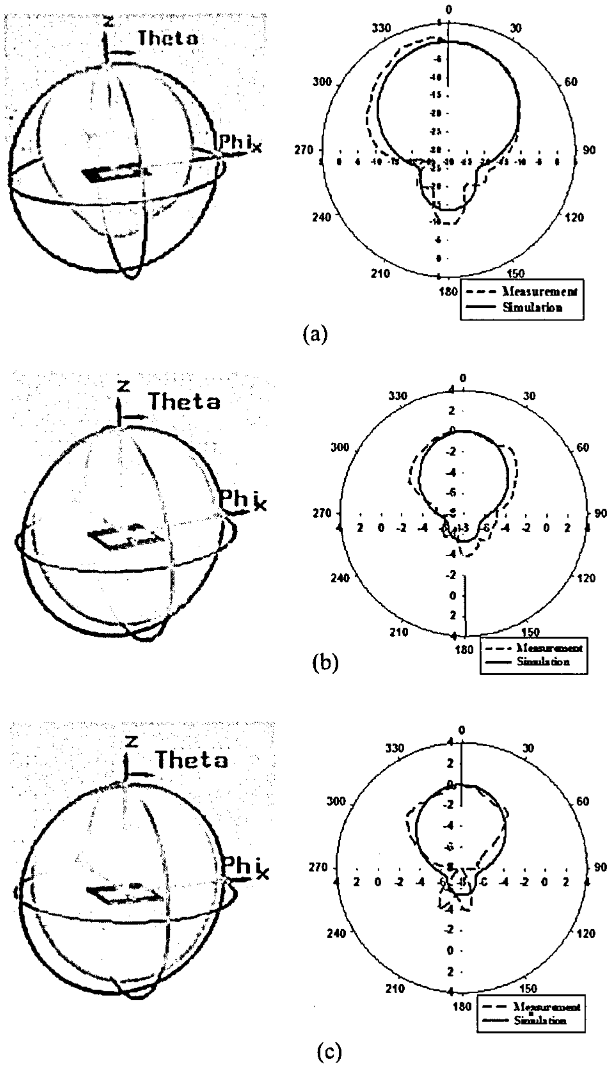


Figure 6: Simulation and Measurement Radiation Pattern E-Plane: (a) Without DGS; (b) Aeroplane-shaped DGS; and (c) UITM-shaped DGS

V. CONCLUSION

Microstrip patch antenna size reduction with DGS was carried out in this study. An Aeroplane-shaped DGS in the common ground plane of microstrip structure was found to give size reduction of about 65%. For the UITM-shaped DGS, the size reduction was about 64%. It was proven that the embedded antenna with the DGS on the ground plane resulted in a compact antenna. In this study, the performance characteristics of the proposed antenna such as return loss and bandwidth were better compared to the reference antenna.

VI. RECOMMENDATION

Based on the research work carried out in the present study, future work can be carried out using different shape of DGS slot and using proximity coupler fed technique for better size reduction.

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