V-Shape and Circular Ring Defect on Rectangular Patch

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***Abstract* – A V-Shape defect on patch and circular ring defect on the ground plane of a rectangular patch antenna is proposed in this paper for wireless applications. An investigation on the effect of the defected structure had been carried out. The results of the return loss, VSWR, directivity and bandwidth show a better performance compared to a conventional antenna. The return loss of conventional antenna -16 dB has been improved to -26 dB on the v-shape and circular ring defect. A bandwidth was enhances 2 MHz. This antenna operates at frequency 2.45 GHz. A FR-4 substrate with relative permitivitty of 4.3 was used in this design. The substrate and copper thickness is 1.6mm and 0.035mm, respectively. The proposed antenna was simulated using Computer Simulation Technology (CST) software. The design was fabricated. The antenna measured using Vector Network Analyzer (VNA) and comparatively studied with simulation results.**

***Keywords* - Patch antenna, microstrip, Defected Ground Structure (DGS), V-shape**

I. Introduction

MICROSTRIP antennas are low profile, conformable to planar and non planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern and impedance[1]. It is consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side. The patch is generally made of conducting material of copper.

Major disadvantages of microstrip antennas are their low efficiency, low power, high Q, poor polarization purity, poor scan performance, and spurious feed radiation and very narrow frequency bandwidth [1].

Microstrip patch antennas electrically a bit larger than its physical dimension due to the fringing fields. For a good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation [2].

Microstrip patch antennas can be fed by several methods. These methods can be classified into two categories; contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

Defected Ground Structure (DGS) of a microstrip line provides an additional effective inductive component, which enables a microstrip line to have a very high impedance to be realized hence shows a slow-wave characteristics. DGS is realized by etching off a simple shape defected from the ground plane, depending on the shape and dimensions of the defect, the shielded current distribution in the ground plane is disturbed resulting a controlled excitation and propagation of the electromagnetic waves through the substrate layer [3]. The dimension of the DGS was optimized for the band gap at the resonant frequency of the antenna by increase or decrease the width of patch antenna[3].

Slot antennas are used typically at frequencies between 300 MHz and 24 GHz. The slot antenna are designed by cutting out surface which are to be mounted on and have radiation patterns that are roughly omnidirectional (similar to a linear wire antenna). The polarization of the slot antenna is linear. The slot size, shape and its cavity offer design variables that can be used to tune performance.

In designing, the first step is to choose the suitable dielectric substrate with appropriate thickness, h and loss tangent. A thicker substrate, besides being mechanically strong, it will increase the radiated power, reduce conductor loss, and improve impedance bandwidth [4]. However, it will also increase the weight, dielectric loss, surface wave loss, and extraneous radiations from the probe feed.

II. METHODOLOGY

A. Flow Chart

Figure 1 shows flow chart the overall project of designing, simulating microstrip patch antenna.

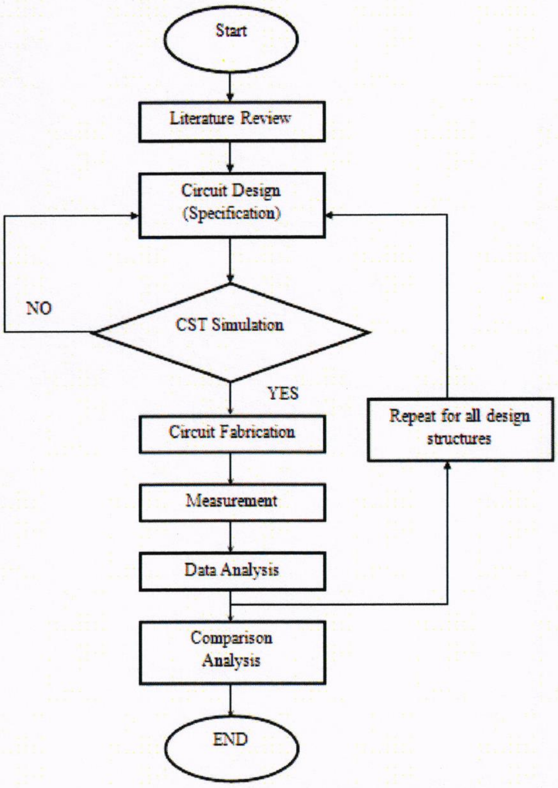


Figure 1: Flow Chart of the Project Design

The implementation of this project includes two main parts which are software design and hardware design. The approaches of the project design are represented in the flow chart in Figure 1. The software simulation includes the designing of conventional antennas and V-shape with circular ring defect on patch antennas. CST Microwave Studio software is used for antenna simulation. The antenna measured using vector network analyzer (VNA) and comparatively studied with simulation results.

B. Structure

Table 1: FR-4 Substrate Properties

Characteristics	Value
Frequency, f_r	2.45 GHz
Substrate	FR-4 (lossy)
Dielectric Constant, ε_r	4.3
Dielectric Thickness	1.6 mm
Copper Thickness	0.035 mm

For the rectangular patch antenna, there are two types of antenna involved. The first antenna is a rectangular patch antenna without DGS which means the conventional antenna, and the other one is rectangular patch antenna with DGS.

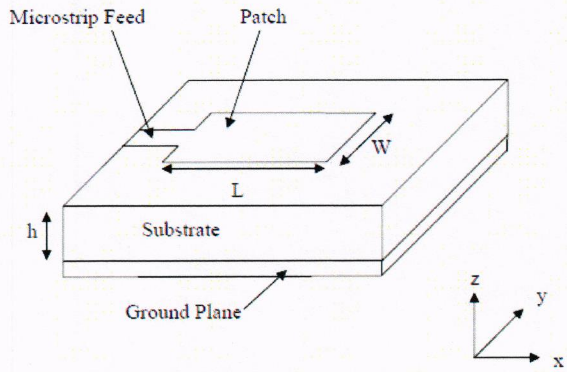


Figure 2: Microstrip Patch Antenna

The width W of the patch is given by

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

Where c = the free space velocity of light
f_r = the resonant frequency
ε_r = the dielectric constant

The effective dielectric constant of the patch is given by

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (2)$$

Where h= the dielectric thickness
W = the width of the patch

The extended incremental length of the patch ΔL is given by

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \qquad (3)$$

Where ε_{reff} = the effective dielectric constant

The actual length L of the patch is given by

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (4)$$

For the feed line, the inset feed technique is being used to match the patch antenna and feed line. This technique makes input impedance easy to control by adjusting the length of the inset [5].

The position of the inset feed point where the input impedance is 50 ohms is given by

$$y_0 = 10^{-4}(0.001699\varepsilon^7 + 0.13761\varepsilon^6 - 6.1783\varepsilon^5 + 93.187\varepsilon^4 - 682.69\varepsilon^3 + 2561.9\varepsilon^2 - 4043\varepsilon + 6697)\left(\frac{L}{2}\right) \quad (5)$$

Computer Simulation Technology (CST) Microwave Studio was used to simulate the circuit that is shown in Figure 3 and 4. From the simulation results, all S-parameters data were collected and analyzed.

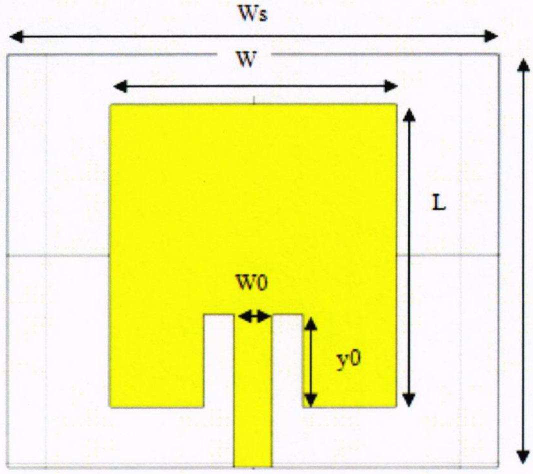


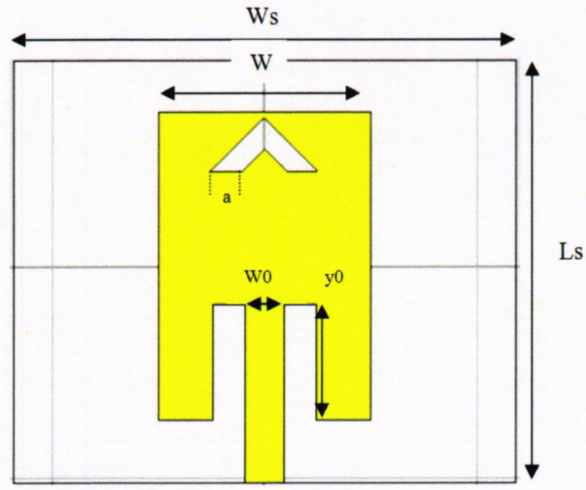
Figure 3: Conventional Antenna

Based on Figure 3, the W is the width of patch and L is the actual length of patch. The value of W_0 is calculated using macros in CST. The conventional patch antenna was then optimized to get the best result. The ground plane of this antenna was then changed with the structure of DGS.

Table 2: Conventional Antenna Parameters

Parameter	Value (mm)
Width Substrate, W_s	47.210
Length Substrate, L_s	39.837
Width Patch, W	37.61
Length Patch, L	29.17
Inset Length, y_0	8.89
Inset Width, W_0	3.68671

Table 2 shows the value of parameter that will use in designing patch antenna. After simulation the result will be optimize to ensure that the line impedance is 50 ohms and the curve of return loss must be at desired frequency of 2.45 GHz. The resonant frequency will change by controlling the width of the patch antenna. Increasing the size of patch antenna, will decrease the resonant frequency or otherwise.



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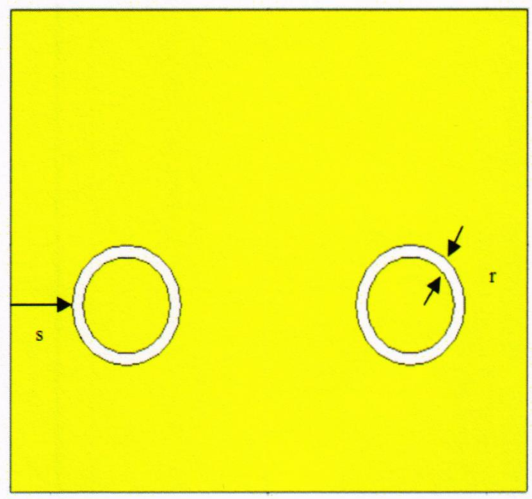

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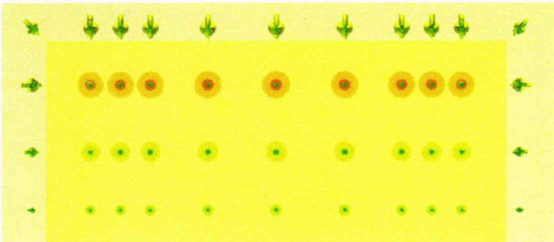
Figure 4: Rectangular V-Shape with Circular Ring DGS; (a) Front View (b) Ground View

The V-shape at rectangular patch is cut at maximum E-field and circular ring DGS is cut at maximum H-field. The result of rectangular V-shape with circular ring DGS is compared with the conventional patch antenna.



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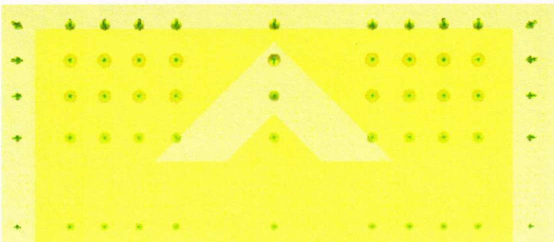

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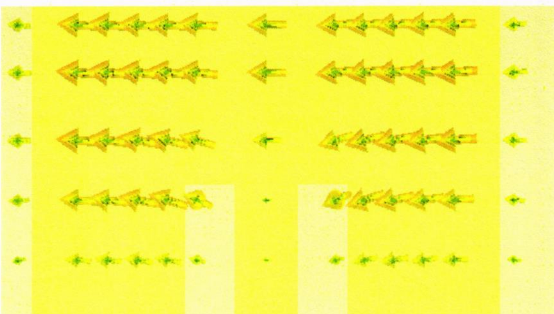
Figure 5: Maximum E-field; (a) Before V-Shape (b) After V-shape



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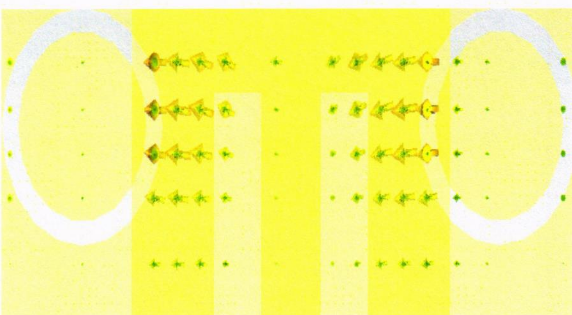


(b)

Figure 6: Maximum H-field; (a) Before DGS (b) After DGS

The electric field of an electromagnetic wave induces a small voltage in each small segment in all electric conductors. The induced voltage depends on the electrical field and the conductor length. The voltage depends also on the relative orientation of the segment and the electrical field.

Antenna patterns indicate how the radiation intensity (E-field, H-field, or power) from an antenna varies in space (usually specified in spherical coordinates). The pattern is usually plotted against one spherical angle (θ or $\emptyset$) at a time.

Table 3: V-shape with DGS Antenna Parameters

Parameter	Value (mm)
Width Substrate, W_s	46.760
Length Substrate, L_s	39.837
Width Patch, W	19.89
Length Patch, L	29.17
Inset Length, y_0	11
Inset Width, W_0	3.68671
Width V-shape, a	3
Width Circular Ring, r	5.805

Table 3 shows the value of parameter that will use in designing rectangular V-shape with circular ring DGS.

III. Results and Discussion

A. Simulation Result

After both antennas have been simulated, the overall results prove that the antenna with DGS has better performances compared to the conventional antenna.

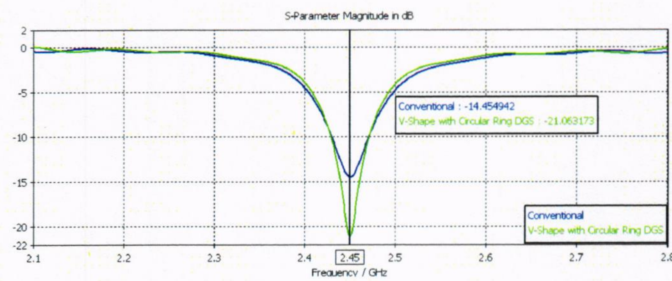
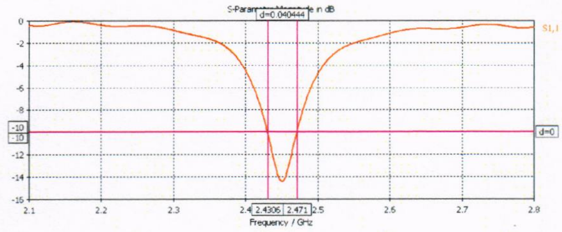


Figure 7: Simulation Result of Return Loss (dB) versus Frequency (GHz)

Figure 7 shows the best value of return loss from both antennas after optimization. The antenna with DGS able to produce value of return loss at the resonant point of -21.06 dB compared to the conventional antenna which is about -14.45 dB. The smallest value of return loss is required in order to minimize the reflection wave and simultaneously able to maximize the transmitting power.



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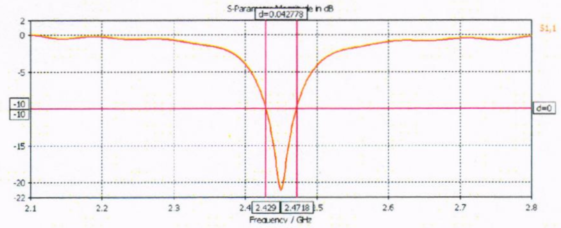

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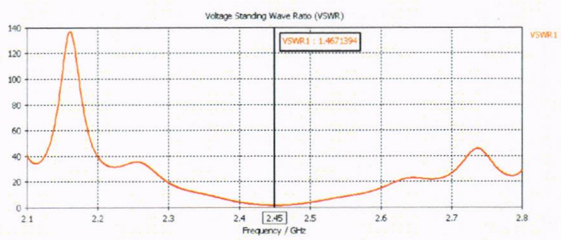
Figure 8: Bandwidth at -10 dB; (a) Conventional Antenna (b) V-Shape with DGS

Figure 8 shows the bandwidth at -10 dB. The bandwidth of conventional antenna and V-shape with DGS is 40 MHz and 42 MHz respectively. The bandwidth has increase 2 MHz after DGS. The bandwidth of the patch antenna is very small. Rectangular patch antennas are notoriously narrowband, the bandwidth of rectangular microstrip antennas are typically 3%.



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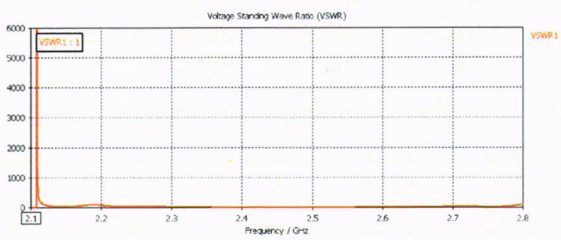
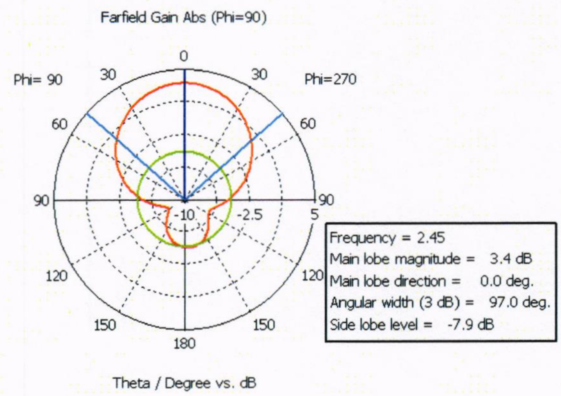


(b)

Figure 9: Voltage Standing Wave Ratio (VSWR); (a) Conventional Antenna (b) V-Shape with DGS

Figure 9 shows the VSWR for both conventional and DGS antennas. The value of VSWR for the conventional is 1.47 and DGS is 1. The VSWR indicates the mismatch between the antenna and the transmission line. For perfect matching the VSWR value should be close to unity.

Beamwidth is the range of angles for which the radiation pattern is greater than 3 dB below its maximum value.



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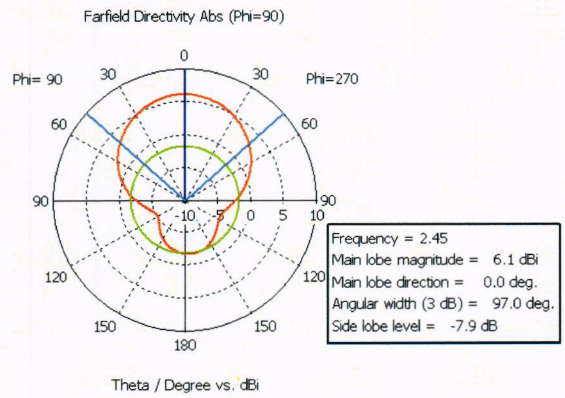

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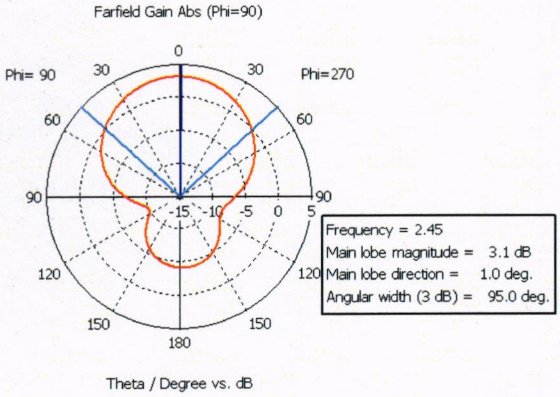
Figure 10: Polar Plot of Conventional (a) Gain (b) Directivity

Figure 10 shows the main focus lobe direction is 0 degree. The main lobe magnitude for gain is 3.4 dB. The main lobe magnitude for directivity is 6.1 dBi.



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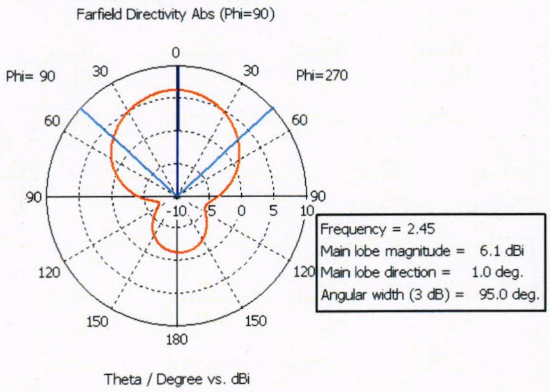


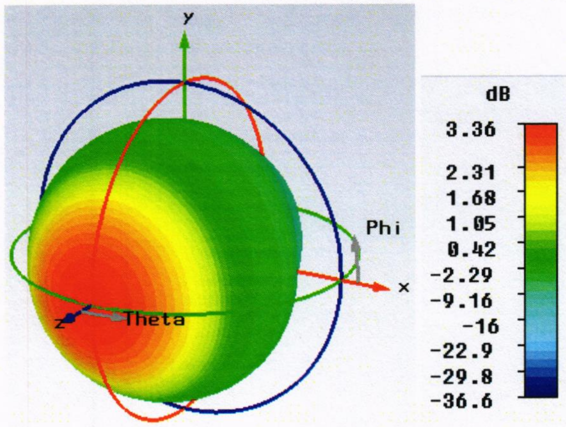
(b)

Figure 11: Polar Plot of V-Shape with DGS; (a) Gain (b) Directivity

Figure 11 shows the gain and directivity polar plot of V-shape with DGS. The main lobe direction, magnitude for gain and directivity is 1degree, 3.1 dB and 6.1dBi, respectively.

The antenna gain can be observed from Figure 12. The conventional antenna shows that the gain is about 3.36 dB which is higher than the antenna with DGS which is only around 3.12 dB.

The antenna gain is the quantity which describes the performance of the antenna or the capability to concentrate energy through a direction to give a better picture of the radiation performance. This is expressed in dB, in a simple word; this refers to the direction of the maximum radiation [6]. The directivity of an antenna can be defined as the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged in all the directions [7].



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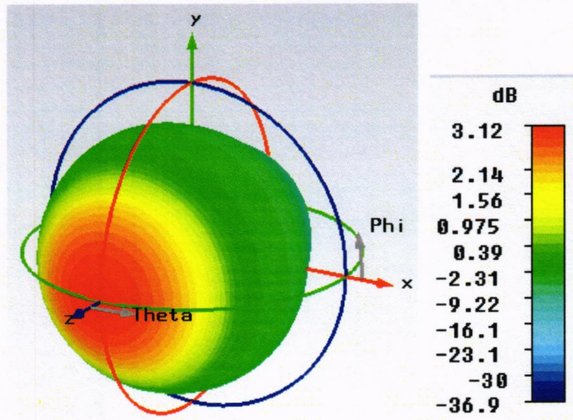

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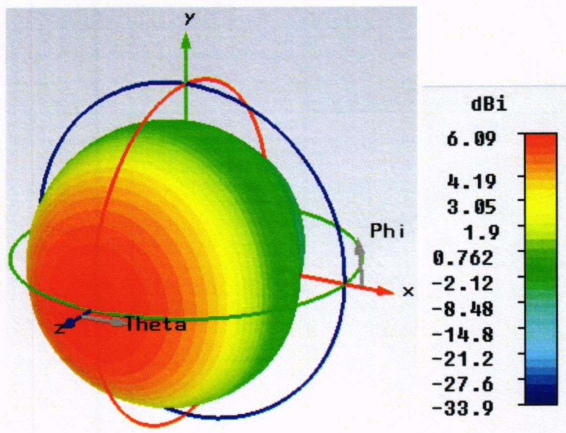
Figure 12: Far field Gain; (a) Conventional (b) with DGS



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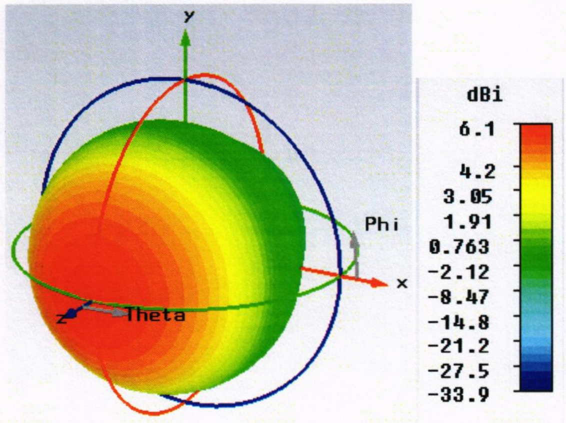

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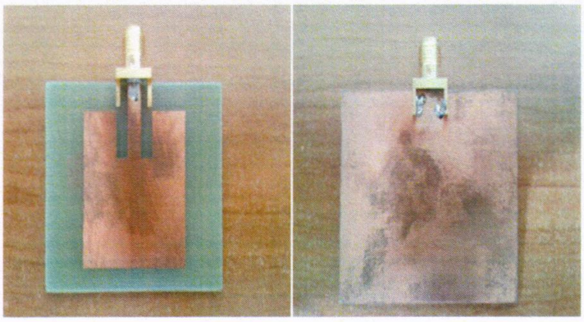
Figure 13: Far field Directivity; (a) Conventional (b) with DGS

The far-field directivity with DGS is higher than the conventional antenna such as shown in Figure 13. The highest value of directivity for antenna with DGS was 6.1 dBi while the conventional antenna was 6.09 dBi.

B. Measurement Result



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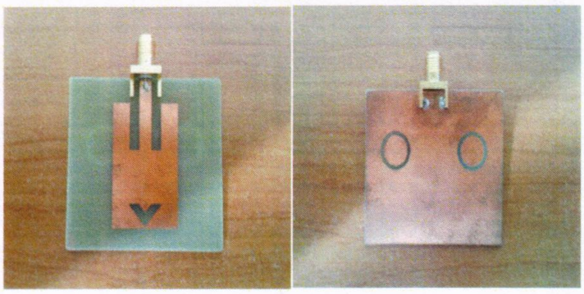

(b)

Figure 14: Fabrication Antenna; (a) Conventional (b) V-Shape with DGS

Figure 14 shows the fabricated conventional patch antenna and rectangular patch with V-shape using circular ring DGS.

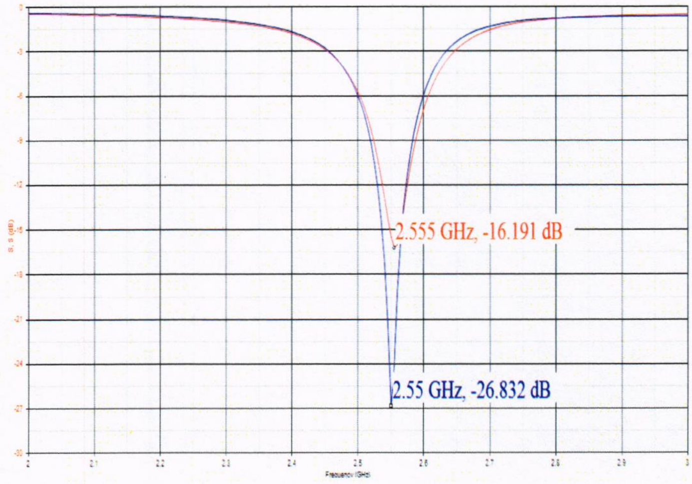

Figure 15: Measurement Result of Return Loss

Figure 15 show the measurement result for the conventional antenna and with DGS antenna using Vector Network Analyzer (VNA). From the result, the return loss for conventional is -16.19 dB at 2.555 GHz, while with DGS antenna is -26.83 dB at 2.55 GHz. The signals have shifted to the right of the resonant frequency compared to the simulation result. This shift due to fringing fields around the antenna, which makes the patch seem longer. Hence, when designing a patch antenna it is typically trimmed by 2-4% to achieve resonance at the desire frequency.

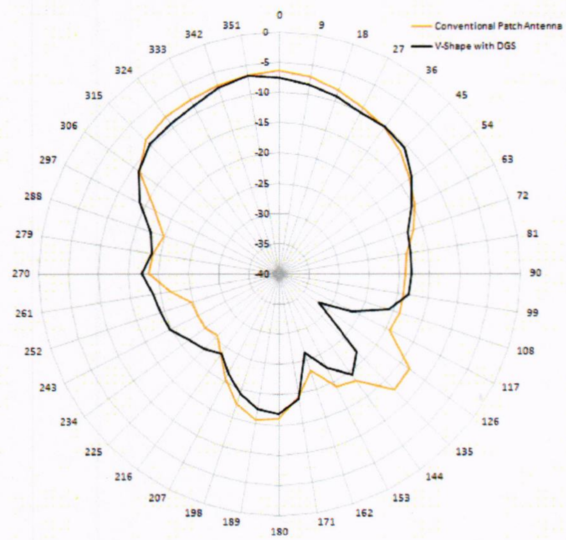

Figure 16: Radiation Pattern of Fabrication Antenna

Figure 16 shows the comparison of radiation pattern between conventional patch antenna and antenna with DGS.

Table 4: Comparison Simulation Performance between Conventional and with DGS

Parameter	Conventional	With DGS
Return Loss, S_{11} (dB)	-14.454942	-21.063173
Gain (dB)	3.36	3.12
Directivity (dBi)	6.09	6.1
VSWR	1.467394	1
Bandwidth (MHz)	40	42

Table 5: Comparison Measured Performance between Conventional and with DGS

Parameter	Conventional	With DGS
Return Loss, S_{11} (dB)	-16.191	-26.832
Bandwidth (MHz)	39	41

IV. CONCLUSION

In this project, the V-shape and circular ring defect on rectangular patch has been successfully designed simulated using the Computer Simulation Technology Microwave Studio (CST-MW). The proposed antenna has been fabricated on FR-4. The fabricated antenna also has been measured by using vector network analyzer (VNA). Each component of the antenna system was optimized to get the best results. DGS structures are proven can improve the performance of the antenna in terms of return loss and bandwidth which increasing 38.5% and 4.8%, respectively. Besides that, by introducing the DGS, the width patch antenna size is reducing about 48.6%. The advantage of a smaller area was that we can reduce the cost in designing microstrip antennas.

V. FUTURE RECOMMENDATION

Some improvements can be done to increase antenna directivity in future research. For future, we can try using array antenna for the simulation to check the directivity. The different substrate and type of patch will affect the antenna performance. DGS structure can be designed in different shape or dimension in order to obtain a better performance. The shape might be used such as circular, rectangular or dumbbell. The circular microstrip patch antenna might also give the effect in enhancing the bandwidth. Antenna performance can also be analyzed using different structure of patches and feeding techniques such as coaxial probe, aperture coupling and proximity coupling.

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