LOW PROFILE WIDE BAND ANTENNA FOR WIDE APPLICATIONS

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ABSTRACT

Antennas are vital for transmitting and receiving signals in RF systems. Microstrip patch antennas (MPAs) are cost-effective and easy to fabricate. However, they face challenges like size reduction and surface wave interference. Metamaterial antennas provide a solution by using unique properties to enhance conventional antennas and enable smaller sizes. This work aims to explore the use of metamaterials, specifically Defected Ground Structure (DGS), to reduce the size of a patch antenna and compare its performance with a conventional antenna. The main objectives of this work are to demonstrate the concept of metamaterials, reduce the size of a rectangular patch antenna by incorporating metamaterial as a substrate, and compare the performance of the DGS-based antenna with a conventional antenna

Keywords: Antennas, Microstrip patch antennas, Metamaterial antennas, Conventional antenna, Defected Ground Structure (DGS)

I. INTRODUCTION

Antenna is one of the important elements in the RF system for receiving or transmitting signals from and into the air as medium. Without proper design of the antenna, the signal generated by the RF system will not be transmitted and no signal can be detected at the receiver. Antenna design is an active field in communication for future development. Many types of antenna have been designed to suit with most devices. One of the types of antenna is the microstrip patch antenna (MPA). The microstrip antenna has been said to be the most innovative area in the antenna engineering with its low material cost and easy to fabricate which the process can be made inside universities or research institute. The idea of microstrip antenna was first presented in year 1950's but it only got serious attention in the 1970's Due to MPA advantages such as low profile and the capability to be fabricated using lithographic technology, antenna developers and researchers can come out with a novel design of antenna which will reduce the cost of its development. Through printed circuit technology, the antenna can be fabricated in mass volume which contributes to cost reduction.

MPA are planar antennas used in wireless links and other microwave applications. It uses conductive strips and patches formed on the top surface of a thin dielectric substrate separating them from a conductive layer on the bottom surface which is the ground for the antenna. A patch is typically wider than a strip and its shape and dimension are important features of the antenna. MPA are probably the most widely used antennas today due to their advantages such as light weight, low volume, low cost, compatibility with integrated circuits and easy installation on the rigid surface. Furthermore, they can be easily designed to operate in dual-band, multi-band application, dual or circular polarization. They are important in many commercial applications. They are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. These low profile antennas are also useful in aircraft, satellites and missile applications, where size, weight, cost, ease of installation, and aerodynamic profile are strict constraints. MPA with inset feed has been studied extensively over the past two decades because of its advantages. However, length of MPA is comparable to half wavelength with single resonant frequency with bandwidth around 2%. Moreover, some applications of the MPA in communication systems required smaller antenna size in order to meet the miniaturization requirements. So, significant advances in the design of compact MPA have been presented over the last years. Many methods are used to reduce the size of MPA like using planar inverted F antenna structure (PIFA) or using substrate with high dielectric constant . Defected Ground Structure (DGS) is one of the methods to reduce the antenna size.DGS is relatively a new area of research and application associated with printed circuit and antennas. The evolution of DGS is from the electron band gap (EBG) structure . The substrate with DGS must be designed so that it becoming metamaterial. The substrate with DGS is considered as metamaterial substrate when both relative permittivity, ε_r and permeability, μ_r are negative. The invented metamaterial antenna will have comparable performance and smaller sizeto conventional one. The substrate that we used was RO3003. The metamaterial antenna behaves as if it were much larger than it really is. By designing the antenna with the DGS makes possible to reduce the size for a particular frequency as compared to the antenna without the DGS. MPA inherently has narrow bandwidth and bandwidth enhancement is usually demanded for practical applications, so for extending the bandwidth, DGS approaches can also be utilized.

II. PROBLEM STATEMENT

In the micro-strip antenna application, one of the problem is to reduce its size while having considerable performance. Moreover, the propagating of surface wave will reduce the efficiency of the antenna. This is due to the increment of the side and back radiation. When this happen, the front lobe or main lobe will decrease which lead to reduction in gain.

III. METHODOLOGY

1. DGS Structures

Before designing the antenna with DGS substrate, two DGS structures were designed first. The target parameter is for the substrate to behave as metamaterial at 4.75 GHz and 2.45 GHz. The characteristics parameters of the substrate are described in the Table 1. RO3003 has good permittivity accuracy with deviations of only 0.04 mm. The substrate thickness is 0.5 mm. The loss tangent is a parameter of a dielectric material that quantifies its inherent dissipation of electromagnetic energy. This substrate has low tangent loss which is 0.0013. Lower tangent loss means lower signal loss. Thus the substrate is suitable for antenna design.

Characteristics	Values
Permittivity, ε_r	3.00 ± 0.04
Permeability, μ_r	1.00
Loss tangen, *tan theta*	0.0013
Thickness, *h*	0.5 mm
Copper cladding, *t*	0.035 mm

Table 1: Characteristic parameter of substrate (RO3003)

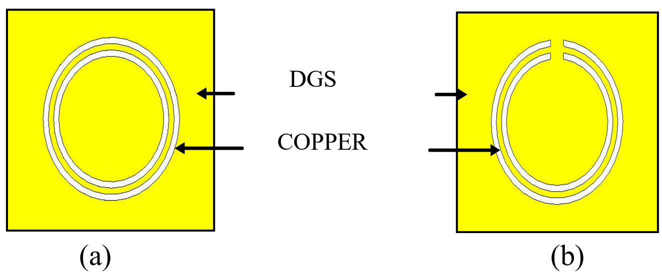


Figure 1: bottom view of DGS strucures (a) circular rings behave as metamaterial at 4.75GHz, (b) split rings behave as metamaterial at 2.45 GHz.

2. Flow chart of design methodology

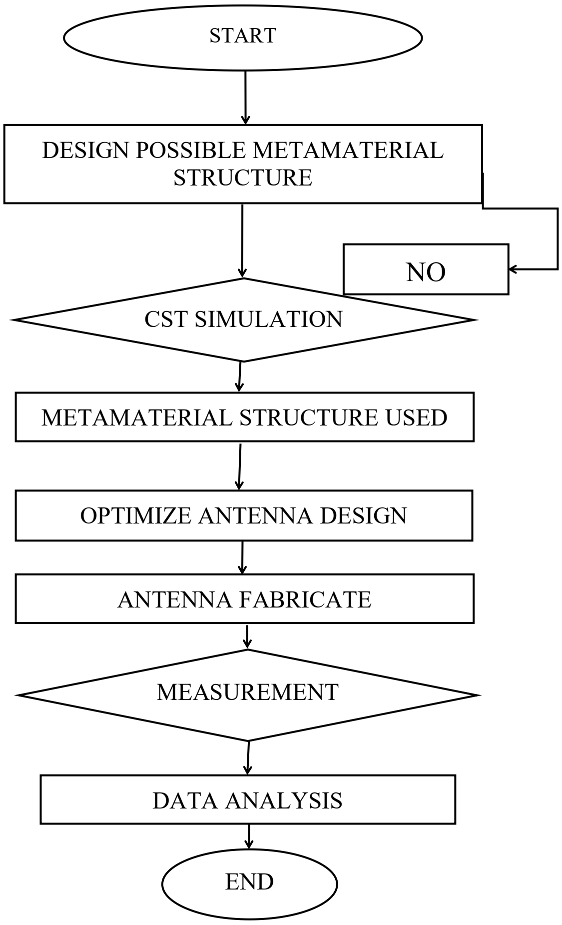


Figure 2 : Flow chart of design methodology

3. Investigation of metamaterial substrate

The designing of DGS antennas are implemented by finding the metamaterial response of the substrate having both permittivity, ε_r and permeability, μ_r negative at desired frequency. The bottom copper of Rogers 3003 must be critically shaped for this purpose.

The transmission line method is selected for analysis purposes as shown in figure 3. The substrate two-port S-parameter was extracted using this technique in simulation. The NRW method act as a converter to obtain the permittivity, ε_r and permeability,μ_r of the material.

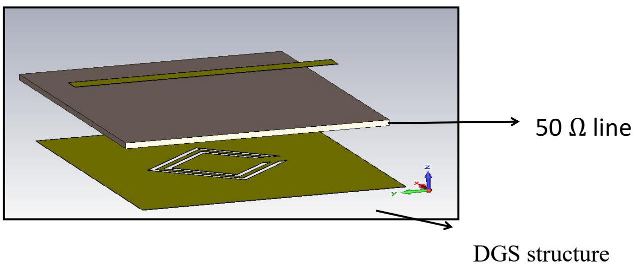


Figure 3. Transmission line method

As mention before the value of permittivity and permeability of the substrate can be changed, influenced by introducing DGS. The location of negative permittivity, ε_r and permeability, μ_r were observed base on NRW calculation. Microsoft Excel was used to make calculation faster. Optimization was done so that the substrate becomes metamaterial at desired frequency.

In figure 4 the blue line represents the permittivity, ε_r value and the red line represents permeability, μ_r value. Figure shows that for circular rings structure having both permittivity and permeability becoming negative at 4.7 GHz frequency band. Therefore, we can realize that this substrate operate as metamaterial at 4.7 GHz. Moreover, this substrate also operates as metamaterial at higher frequency. As we can see at 9.6 GHz, both electrical properties are negative.

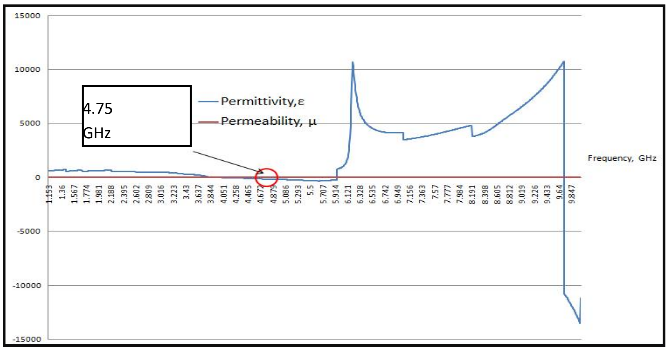


Figure 4 : 4.75 GHz, Relative permittivity $\varepsilon_r = -154$, permeability $\mu_r = -0.000818$, relative permeability value versus frequencies for substrate with circular rings DGS

In figure 5 the blue line represents the permittivity, ε_r value and the red line represents permeability, μ_r value. Figure shows that for circular rings structure having both permittivity, ε_r and permeability, μ_r becoming negative at 2.4 GHz frequency band. Therefore, we can realize that this substrate operate as metamaterial at 2.4 GHz. Moreover, this substrate also operates as metamaterial at higher frequency. As we can see at 9.6 GHz, both electrical properties are negative.

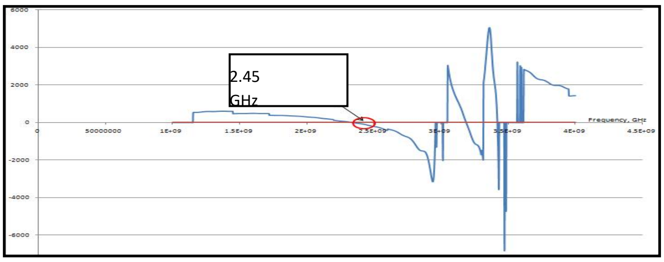


Figure 5 : 2.45 GHz, Relative permittivity $\varepsilon_r = -132$, permeability $\mu_r = -0.000461$, relative permeability value versus frequencies for substrate with circular rings DGS

Final physical parameters of both substrates are shown in figure 6. These substrate structures had been tuned to get the metamaterial functional at desired frequencies. Figure 6 shows two rings with inner radii of 5 mm and 6 mm. Both of the rings have 0.5mm width operate with 4.7 GHz and 2.45 GHz. The rings have 1.29 mm gap.

The slip rings structure is a modification made from double rings so that the substrate behaves as metamaterial at 2.45 GHz. The 1.29 mm gap increase the copper area thus increases the total capacitance value.

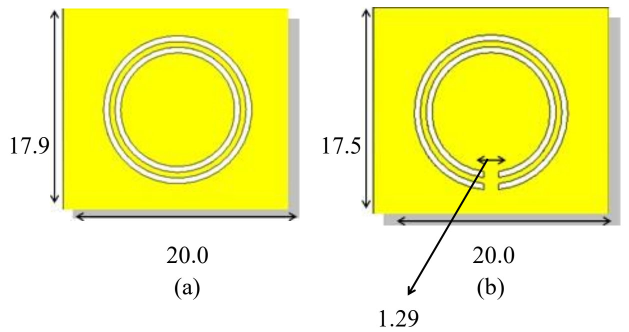


Figure 6: Designed metamaterial substrates dimension(mm)(a) double rings and (b) slip ring physical parameter

4. Antenna design

a. Designing rectangular patch antenna

The simulation of conventional antenna is designed for the purpose of comparison to DGS one. Two conventional MPA antennas were designed at 4.75 GHz and 24 GHz respectively.

The objectives of the antenna design are described in table 2. The antenna design should have the value of return loss is less than negative 10dB. Specifically, the return loss should be as low as possible to reduce the matching independence. Moreover , the design antenna should have linear polarization.

Frequency of operation	4.7 GHz and 2.4 GHz
Return loss (dB)	<-10dB
Feeding method	Microstrip line
Polarization	Linear

Table 2 : Characteristic goals of conventional rectangular patch antenna

Based on simulation each of conventional rectangular patch antenna are able to operate at 4.75GHz and 2.4GHz respectively. The dimension is as shown in figure 7(A) and 7(B). The simulation template used was Antenna (mobile phone) which have the following default settings as table 3. The setting units of mm and GHz in simulation aredue the ease of simulation. The boundaries of simulation are set to free space for all direction. These settings are used to calculate the far-field radiation pattern so that the antenna surrounding set as open space.

Measurement unit length	mm
Measurement unit frequency	GHz
Boundaries	Free space

Table 3: Settings for CST MWS

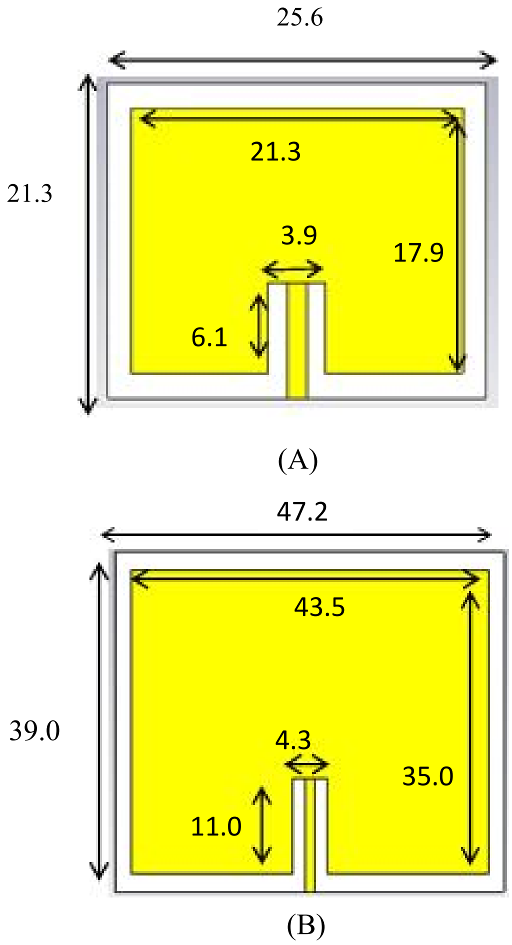
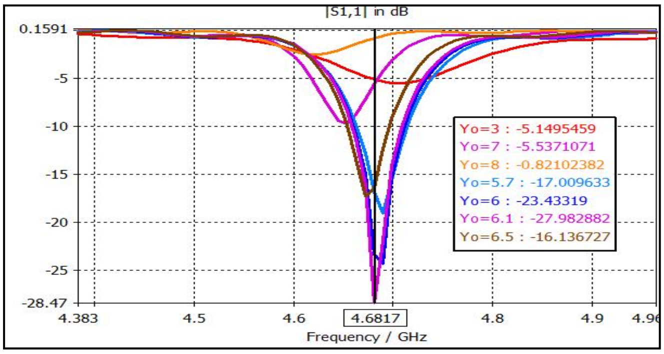


Figure 7: Top view dimensions (mm) of conventional rectangular patch antenna : (A) 4.75 GHz antenna (B) 2.4 GHz antenna

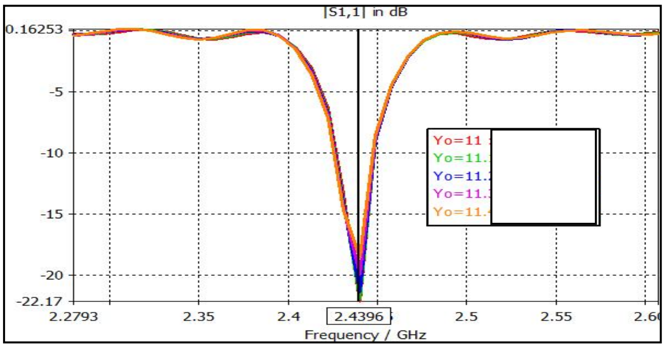
The simulation was done from 1GHz to 10 GHz . All the calculation of EM field done using ‘transient saver, with default settings. The optimization was done so that the antennas having lowest reflection coefficient at the desired frequency. The length of inset cut were tune to get result.

Figure 8(A) shows return loss of 4.7 GHz conventional patch antenna having different inset cut length. Changing the length of inset cut will change the impedance value. Different values of inset cut length are observed for the purpose of optimization. Having short inset length such 3.0 mm the return loss is negative 5.1 dB and with deeper inset length of 6.5 mm the return loss become negative 16.1 db. The best inset length is 6.1 mm with return loss of negative 28.0 dB.

Figure 8(B) shows return loss of 2.4 GHz conventional patch antenna has different inset cut length . Having inset length of 114 mm the return loss becoming negative 18.3 db. The best inset length is 11 mm with return loss negative 21.7 db. Thus it can be understood that if the inset cut is far from the matching impedance the return loss will increase.



(A)



(B)

Figure 8: Result of return loss simulation on variations inset cut length for conventional rectangular patch antenna : (A) 4.7 GHz antenna (B) 2.4 GHz

Design parameters	Comment
Inset cut length	Need specific length, longer or shorter increase the reflection coefficient
Antenna Width	Reduce width = increase resonance frequency Increase width = reduce the resonance frequency
Antenna length	Reduce length = increase the antenna resonance frequency Increase length = reduce the resonance frequency

Table 4 : Antenna design optimization [table 4 summarized the physical parameters that change the antenna performance]

5. Designing rectangular patch antenn with DGS

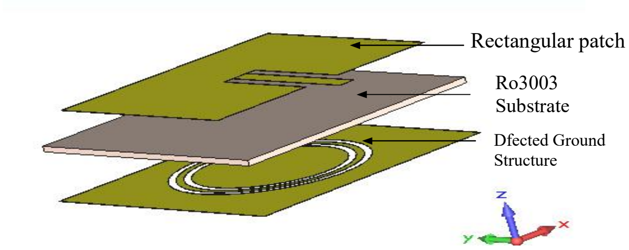


Figure 9 : 3D structure of DGS antenna

The metamaterial antennas were designed using two DGS substrates that were discussed before. The 2 rings structure used to implement metamaterial antenna that operates at 4.75 GHz and the slip rings at 2.45 GHz . Then the patch size including the length , width was tuned so that the antenna operates at the desired frequency, moreover the inset cut was also tuned to obtain the best match impedance.

6. Fabrication process

It includes 5 steps,
1. Generate mask on transparency film
2. Photo exposure process
3. Etching in developer solution
4. Etching in Ferric chloride
5. Soldering the probe

1. Generate mask on transparency film
First step is to transfer the antennas top and bottom layer structure into .DXF format that is compatible with Auto-Computer Added Drawing (AutoCAD) and print it onto the transparency film.

2. Photo exposure process
Second step is the Ultraviolet exposure process. It is done to transfer the image of the circuit pattern with a film in a UV exposure machine onto to the photo resist laminated board.

3. Etching in developer solution
The third step is to ensure the pattern will be fully developed, during the developing process. The photo resist developer solution was used to wash away the exposed resist. Then the solution was removed by spray wash. In this process, water was added with Sodium Hydroxide (NaOH).

4. Etching in Ferric chloride
Fourth step is the etching in ferric chloride. It will remove the unwanted copper area and this process was followed by the removal of the solution by water.

5. Soldering the probe
The second process in fabrication is soldering process. This process only can be done after the etching process has finish. In this process, a port and a solder will be used. The soldering process actually is to connect the port to the antenna. After that, the feeder will be soldered together with the antenna. 1mm SMA connecter was soldered to the microscopic antenna.

7 . Measurements

The measurement is done to investigate the performance of the fabricated antenna. The return loss and the radiation pattern are analyzed and investigated. From the return loss, we also can observe the transmission loss and bandwidth. Then, the measurement will be compared to the simulation. The return loss was measured using Vector Network Analyzer (VNA). The equipment was calibrated before taking any measurements. One- port scattering parameter for both conventional and DGS antenna were measured. Then, all the measurement data was stored.

The radiation patterns were measured in anechoic chamber room. Anechoic chamber are guarded with absorbers located around the walls. The absorbers are used to absorb the unwanted signal to reduce the reflected signal. It can increase the efficiency of the measurement process. The equipments were divided into two sections. The first section consist of the horn antenna and VNA, the second section consist of a spectrum analyzer, a positioner and a rotator.

The first section is the transmitter part and the second section is the receiving part. The antenna under test (AUT) will be placed at the rotator. The positioner will control the rotator to rotate the tested antenna from 0 degrees to 360 degrees. The received signal of the antenna will be measured by the spectrum analyzer at different angle in the term of signal to noise ratio. This measurement is done to see the radiation pattern of the antenna. To use these device, the experience user is needed to guide inexperience user to use these device because it can make hazardous effect by higher frequency and quite expensive.

Figure 10 shows all the connection of the devices for anechoic chamber. The VNA is connected to reference antenna (horn antenna). The rotator are connected to the antenna under test (AUT). From that the measurement value decision can be made whether the value is same from the expected requirement.

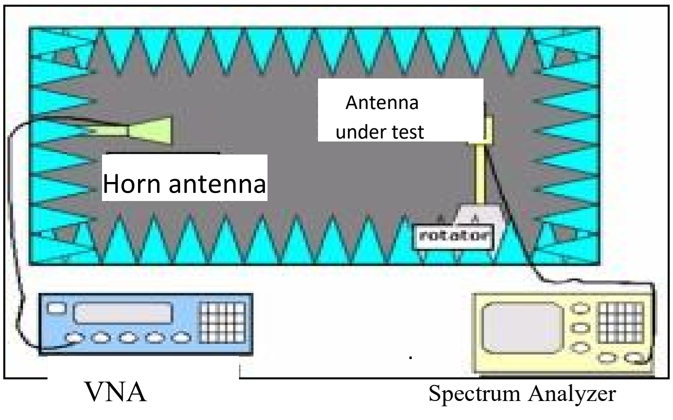


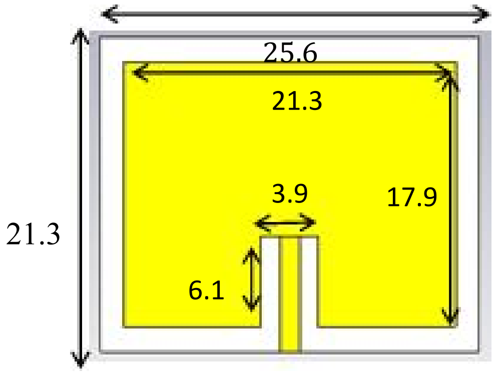
Figure 10 : Anechoic chamber

IV . RESULT AND DISCUSSION

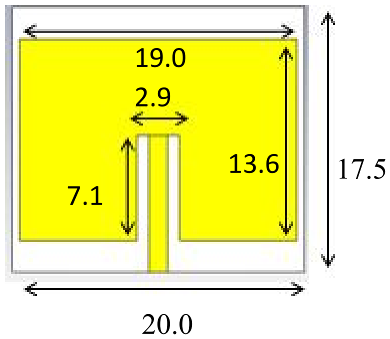
1) 4.75 GHz Antennas

Antenna Parameters

The simulation result shows metamaterial antenna can reduce the size of rectangular patch antenna. The antenna with circular rings DGS can reduce the size upto 34.3%.



(a)



(b)

Figure 11: Top view dimension of the of 4.7 GHz antennas (a) conventional (b) metamaterial antenna with circular rings DGS.

Simulation : Return loss comparison between conventional and DGS

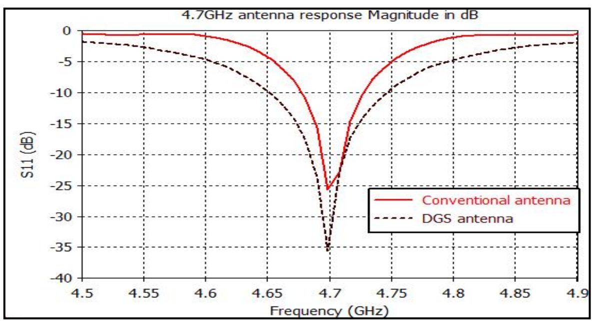
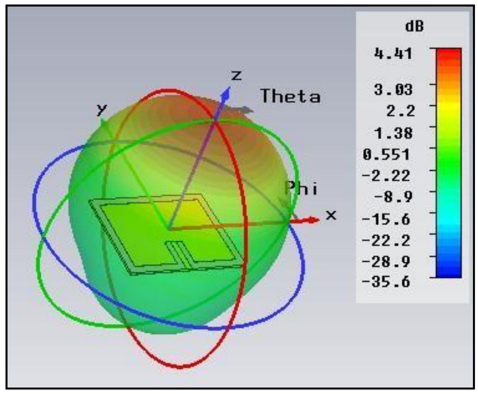
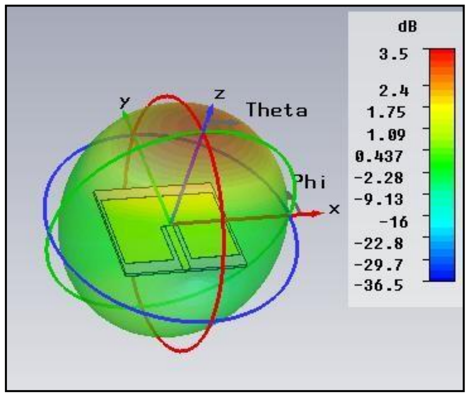


Figure 12 : Comparison of return loss simulation data between conventional antenna and DGS metamaterial antenna

Simulation : Radiation pattern of 4.75 GHz Antennas



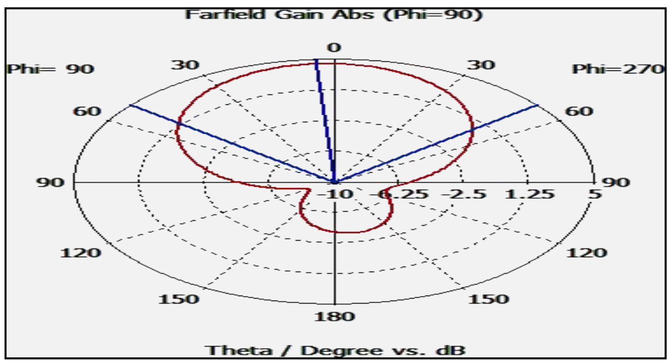
(A)



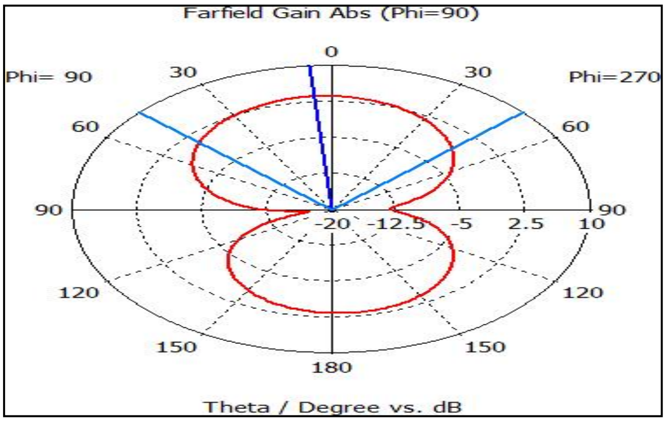
(B)

Figure 13: 4.7 GHz Radiation pattern of conventional antenna , (A) : 3D Conventional antenna,(B) : 3D antenna with DGS

Figure 13 (A) and 13 (B) shows the 3D radiation pattern for the conventional antenna and DGS metamaterial antenna at 4.7 GHz. The simulated gain for the DGS metamaterial antenna is 3.5 dB as for the conventional antenna the simulated gain is 4.41 dB. This shows that DGS antenna have considerable gain as compared to conventional one.



(A)



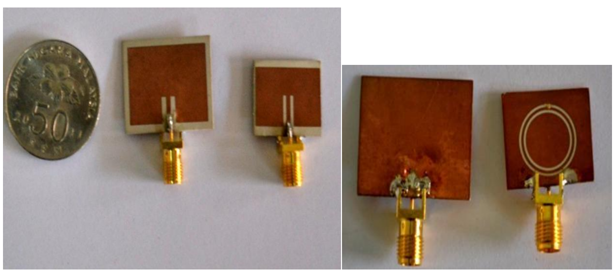
(B)

Figure 14 : 4.7 GHz radiation pattern ,(A) : Polar plot conventional antenna, (B) : Polar plot DGS antenna, [beam main lobe direction for conventional antenna is 4 digree with beam width = 102.5 digree,beam main lobe direction for DGS antenna is 5 digree with beam width = 95.4 digree]

Parameter	4.7GHz Conventional antenna	4.7GHz DGS antenna
Return loss,dB	-25.7	-35.6
Bandwidth, MHz	50.7	97.2
Gain, dB	4.41	3.5
Directivity, dB	6.3	4.28
Size, mm^2	545.28	358
Total Efficiency, %	64.4	83.6

Table 5: Comparison Between 4.7GHz Conventional and DGS Antenna

Size Comparison



(a) (b)

Figure 15 :Size comparison of fabricated 4.7 GHz antenna(a) front view (b) bottom view

This shows the size comparison between conventional, DGS antenna and 50 cent Malaysian coin. These antennas operate at 4.7 GHz. These antennas are connected with SMA connector. The smaller antenna is the 4.7 GHz metamaterial antenna. The metamaterial antenna has a DGS structure at the ground.

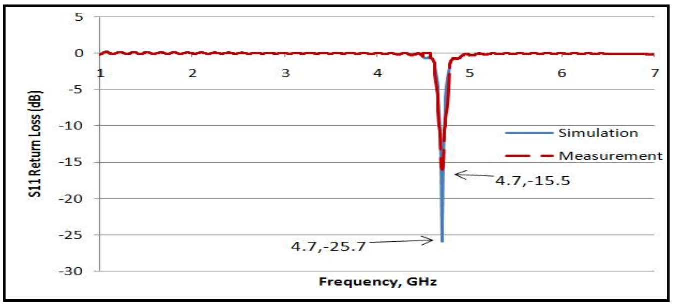


Figure 16: Graph simulation and measurement of 4.7 GHz conventional antenna versus frequency.

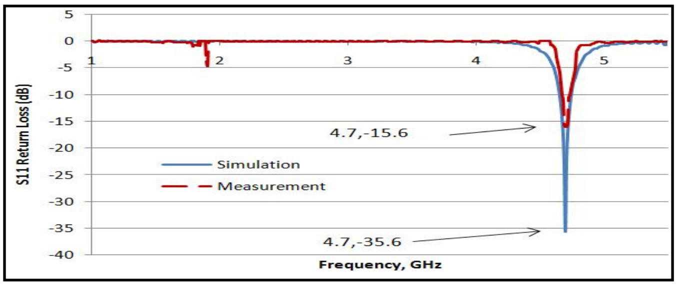


Figure 17 : Graph simulation and measurement of 4.7 GHz DGS antenna versus frequency.

Figure 16 shows the comparison between measurement and simulation result of 4.7 GHz conventional antenna. The measurement shows negative 15.5 dB return loss which is higher compared to the simulation with negative 25.7 dB. The fabricated antenna operates at 4.7 GHz which is in good agreement with simulation.

Figure 17 shows comparison between measurement and simulation result of 4.7 GHz conventional antenna. The measurement shows negative 15.5 dB return loss which is higher compared to the simulation with negative 25.7 dB. The fabricated antenna operates at 4.7 GHz which is in good agreement with simulation.

Comparison between conventional and DGS Antenna

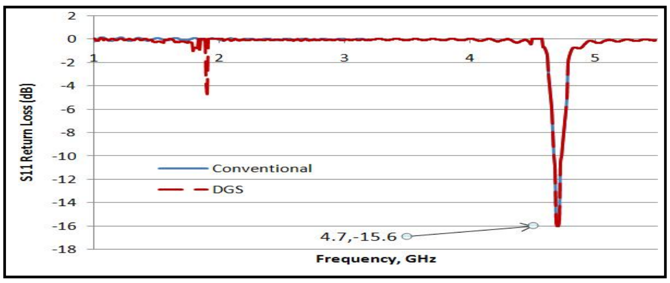


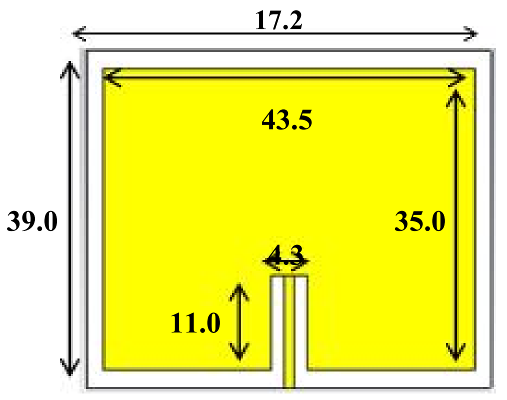
Figure 18 : Graph comparing between 4.7 GHz conventional and DGS antennas

It can be concluded from the S11 comparison graphs that the resonant frequencyhas shifted in the magnitude from the designed frequency for most of the designs. The root cause of the shift is could be due to the patch and substrate dimension that varies infabrication process.

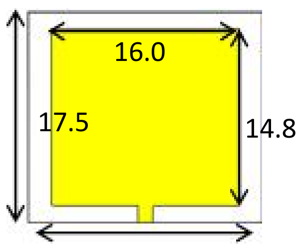
2) 2.4 GHz Antennas

Antenna parameters

The simulation result shows metamaterial antenna can reduce the size of rectangular patch antenna. The antenna with circular rings DGS can reduce the size upto 80%.



(a)



20.0

(b)

Figure 19: Top view dimension (mm) of the of 2.4 GHz antennas (a) conventional (b) metamaterial antenna with slips rings DGS

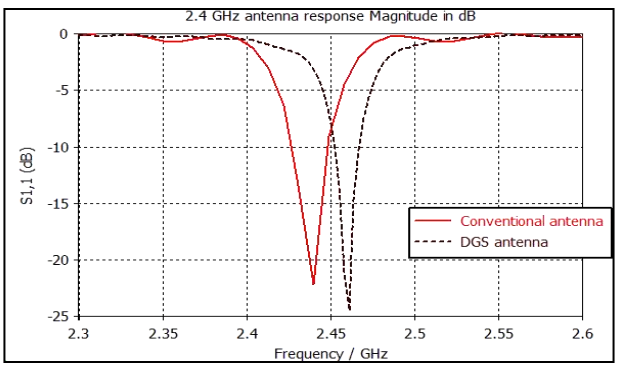
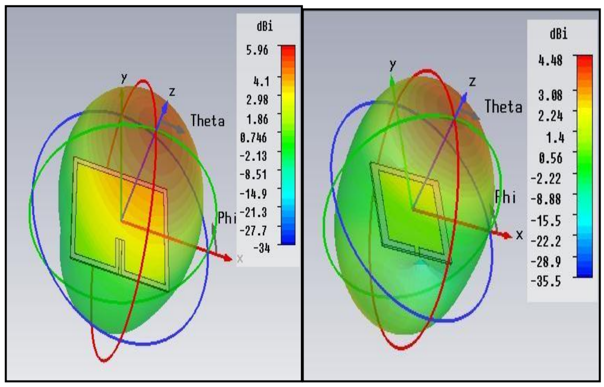


Figure 20 : Comparison of return loss simulation data of conventional antenna and DGS metamaterial antenna

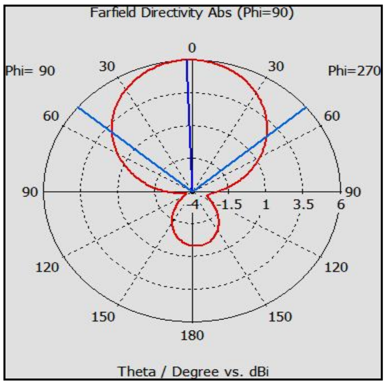
Figure 20 describes that return loss S11 response of metamaterial microstrip patch antenna compared to return loss S11 response of conventional antenna. Noticed that the DGS antenna return loss is -24 dB compared to the simulated simulated result of patch antenna without DGS which is just -22 dB. The operating frequency of DGS antenna is between 2.452 GHz to 2.468 GHz. The bandwidth of DGS antenna is 15 MHz which is smaller than conventional antenna which is 21.6 MHz Notice that 2.4GHz DGS antenna have to compensate bandwidth by 30.56%.

Simulation : Radiation pattern of 2.4 GHz antenna

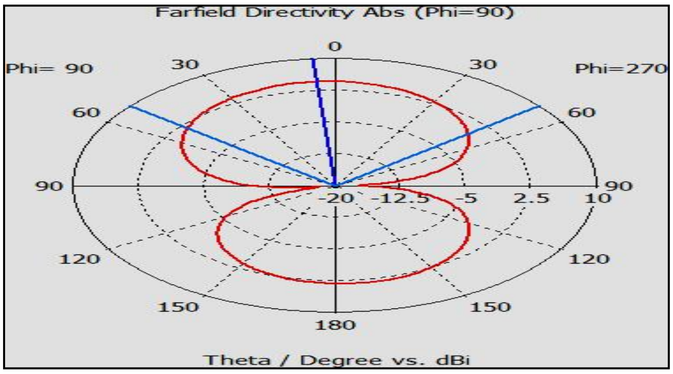


(A) (B)

Figure 21 : 2.4 GHz Radiation pattern of conventional antenna , (A) : 3D Conventional antenna,(B) : 3D antenna with DGS



(A)



(B)

Figure 22: 2.4 GHz radiation pattern ,(A) : Polar plot conventional antenna, (B) : Polar plot DGS antenna.

Figure 21 (A) and (B) show the 3D radiation pattern for the conventional antenna and DGS metamaterial antenna at 2.4 GHz. The simulated gain for the DGS metamaterial antenna is 4.48 dB as for the conventional antenna the simulated directivity is 5.96 dB .

Figure 22 (A) and (B) show the polar plot for the conventional antenna and DGS metamaterial antenna. The beam main lobe direction for conventional antenna is 2 degree with beam width 100.2 degree. The beam main lobe direction for DGS antenna is 5 degree with beam width 102.3 degree.

Parameter	2.4 GHz conventiona lantenna	2.4 GHz DGS antenna
Return loss,dB	-22.1	-24.1
Bandwidth, MHz	22.7	15.2
Gain, dB	1.88	-10.9
Directivity, dB	5.96	4.48
Size, mm^2	1840.8	350
Total Efficiency, %	38.8	2.9

Table 6: Comparison Between 2.4GHz Conventional and DGS Antenna

Table 6 describes all data obtained from simulation in CST Microwave Studio. The directivity of DGS metamaterial antenna is 4.48 dB slightly less than directivity of conventional antenna that has 5.96 db of directivity due to the introduction of DGS. Based on the data analyzed, it can be concluded that the performance of both the antenna through simulation more less the same.

Size comparison

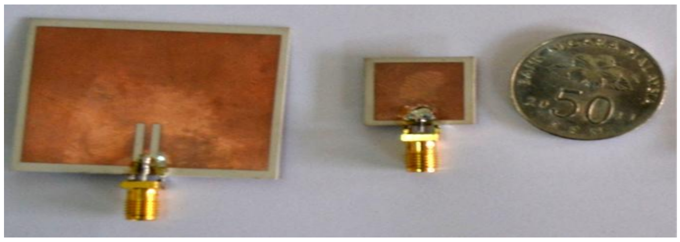


Figure 23: Size comparison of fabricated 2.4 GHz antenna

Figure 23 shows the size comparison between conventional, DGS antenna and 50cent Malaysian coin. The smaller antenna is the metamaterial antenna. These antennas operate at 2.4 GHz. These antennas are connected with SMA connector.

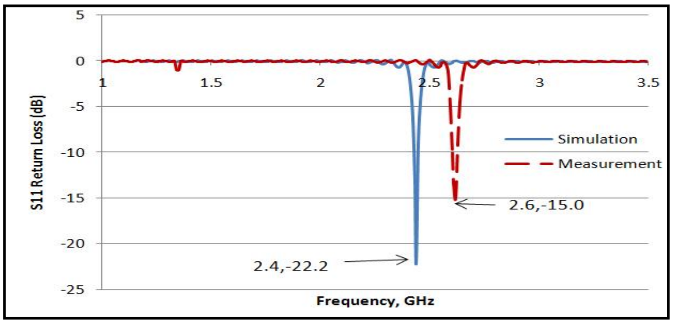


Figure 24: Graph simulation and measurement of 2.4 GHz conventional antenna versus frequency.

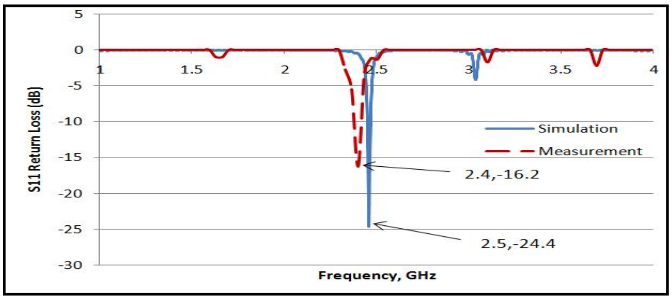


Figure 25 : Graph simulation and measurement of 4.7 GHz DGS antenna versus frequency.

Figure 24 shows comparison between measurement and simulation result of 2.4GHz conventional antenna. The measurement shows negative 15.0 dB return loss which is higher compared to the simulation with negative 22.2 dB. The fabricated antenna operates at 2.6 GHz which is in good agreement with simulation. Noticed that the fabricated antenna operates at higher frequency. Figure 25 shows comparison between measurement and simulation result of 4.7GHz conventional antenna. The measurement shows negative 15.5 dB return loss which is higher compared to the simulation with negative 25.7 dB. The fabricated antenna operates at 4.7 GHz which is in good agreement with simulation.

Comparison between conventional and DGS antenna

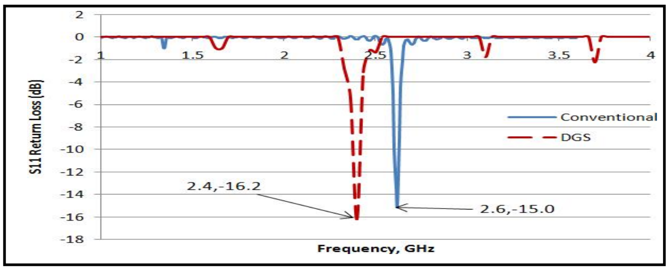


Figure 26: Graph comparing between 2.4 GHz conventional and DGS antenna.

Figure 26 shows the comparison of 2.4 GHz DGS and conventional antenna that have fabricated and measured. Figure 4.15 describes the return loss S_{11} response of metamaterial microstrip antenna compared to return loss S_{11} response of conventional antenna. Notice that the rectangular patch antenna with DGS having comparable return loss which is -15.6dB. The DGS antenna operates at lower frequency compared to conventional one.

Based on the data, the dimension of a microstrip patch antenna operating at 4.7 GHz had been successfully reduced up to 34 % of the original dimension while having larger bandwidth. Moreover, 2.4 GHz metamaterial antenna is able to reduce the size up to 80% but having poor performance. Here noticed that the reflection coefficient reduced and shift in all measurements. This is due to the poor matching which related to the introduction of SMA connector, soldering and accuracy of etching process. However, overall the measurement values are comparable to the simulation result.

V . CONCLUSION

The goals of this project is to design two miniaturized rectangular patch antenna that operate at 4.75 GHz and 2.4GHz frequencies using metamaterial substrate. The antennas fabricated expected of having comparable or better performance to the conventional one. The conventional microstrip antenna was designed as a reference with a microstrip line as a feed. The S11 (input return loss) plot for microstrip antennas have a magnitude of much less that –10dB at the operating frequency which means that the matching impedance is achieve.

It is proved that the microstrip antenna with metamaterial substrate can improves the size of the antenna. Moreover, this project proves that DGS can be implemented to alter the electrical properties. As an overall conclusion , all the planned works and objectives have been successfully implemented achieved, even though the performance of the antenna designed do not shows a big different after integrated with DGS structures. But, the improvement of the antenna size and bandwidth still can be noticed.

VI . SUGGESTIONS FOR FUTURE WORKS

In term of DGS structure, the design can be further improve in terms of basic parameters such as type of substrate, dielectric constant, the thickness of the substrate. From this work , we can design the DGS structure for different frequency of operation. Moreover, investigation into designing the microstrip antenna with different patch shapes and sizes are vital.

In term of DGS structure, the design can be further improve The DGS structure also can be applied in the array antenna. This array antenna can be further classified according to the different thickness of the substrate and the variousvalue of dielectric constant. In addition , the slip ring structure DGS should be further study for filter application. In the future different structure of DGS should be design inorder to improve the performance of microwave devices.

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