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BANDWIDTH AND GAIN ENHANCEMENT OF MICROSTRIP ANTENNA USING DEFECTED GROUND STRUCTURE AND HORIZONTAL PATCH GAP

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Abstract
This research proposed microstrip antenna design using the Defected Ground Structure (DGS) and horizontal patch gap (HPG) for bandwidth and enhancement purposes. This design is to reduce the weakness of a microstrip antenna, which has small gain and narrow bandwidth. The design was simulated in CST Microwave Studio with a working frequency of 2.4 GHz. The design consists of three stages model, i.e., conventional design, DGS modification, and the combination DGS using a Horizontal Patch Gap (DGSHPG). The radius of the conventional circular patch is 16.7 mm. The substrate has 4.6 of dielectric constant, 1.6 of substrate height, and 0.025 of the loss tangent. The simulation results show that the DGS design produces more bandwidth and gain than a conventional design, where the bandwidth and gain improvement are 421.2 MHz and 1.73 dB, respectively. The DGS model is combined with a gap that separates the circular patch (DGSHPG) to achieve the optimum design. The results show the bandwidth and gain improvement of more than 50% and 18.1% compared to the DGS design, respectively. Other parameter performance also shows improvement, such as a reflection factor with -53.3 dB at the center frequency. The physical change also influences the patch's radius, where it is reduced around 1.4 mm or 8.4% from the original design. Overall, the proposed design has succeeded in achieving bandwidth and gain enhancement and reducing the patch dimension.

Keywords:
Bandwidth;
DGS;
Gain;
Gap;
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INTRODUCTION

Information technology is increasingly developing, which is in line with the emergence of various new applications that provide convenience for the community. Furthermore, many applications are now available in one device. As an example, in the past, the mobile phone only provides call and message service. Some applications appear, such as internet access from both mobile data and wireless fidelity (Wi-Fi), a Global Positioning System (GPS) and so on. These applications work on certain frequencies. Therefore, equipment should provide antennas that can match those frequencies. One of the antennas that can be established is a microstrip antenna that has been studied to resonate for many applications and cover more than one frequency, such as [1, 2, 3, 4].

The antenna microstrip is a modern antenna massively used and developed for wireless communication, especially spacecraft applications and low profile antenna applications. [5]. This antenna consists of a substrate and thin metallic as a radiating element or as a ground. A patch of microstrip antenna can be created in some forms like rectangular, triangle, and circular. This antenna has some advantages such as inexpensive, lightweight and easy to manufacture. However, its bandwidth is narrow and produces small gain as well as inefficient radiation [6][7]. Hence, this study aims to reduce these weaknesses and will focus on the gain and bandwidth enhancement.

Some papers have researched microstrip antennas in enhancing gain and bandwidth. Research [8] studied the integrated antenna and low noise amplifier for increasing gain. This research used two transistors of NE3509M04 proven effectively, creating high gain in a simple structure. Another research is utilizing a reflecting layer with dimension 55 mm x 60 mm [9]. Its simulation result shows gain improvement. However, it needs some additional structure that can reduce the space of the equipment. A general study of gain improvement methods can be seen in [10] that elaborates the patch structure and microstrip antenna material.

For bandwidth increment, [11] used a Defected Ground Structure method (DGS) that operates at 2.4 GHz of frequency and has 180 MHz of bandwidth. Nevertheless, it still can be improved for wider bandwidth [12]. Gap-coupled of the parasitic patch can also increase bandwidth value, as shown at [13], producing dual resonant frequency. Some studies also proved that gap-couple could widen bandwidth antenna [14][15].

The state of the art of this research is to combine a Defected Ground Structure and Horizontal Patch Gap (DGSHGP) method. The antenna's basic geometry is a circular patch using inset feed for matching frequency to resonate at 2.4 GHz. Further, the antenna design modifies the DGS that expands the bandwidth value. Subsequently, a circular patch with DGS structure puts a gap in the middle of the patch that separates both in a certain dimension. This method is expected to affect the gain and bandwidth of the antenna. Because the gap created a mutually coupled patch that influenced the equivalent circuit's capacitance, this method influenced bandwidth and gain results. Antenna design will be simulated using CST Microwave Studio.

ANTENNA DESIGN AND SIMULATION

Conventional Design

The design of the proposed microstrip antenna has three stages. The first is to build a conventional design using a circular patch by calculating various parameters to determine the patch's radius. This conventional design applies fully metal of the ground in the back of the patch. This antenna also adopts an inset feed for matching at the resonant frequency, as shown in Figure 1 [16].

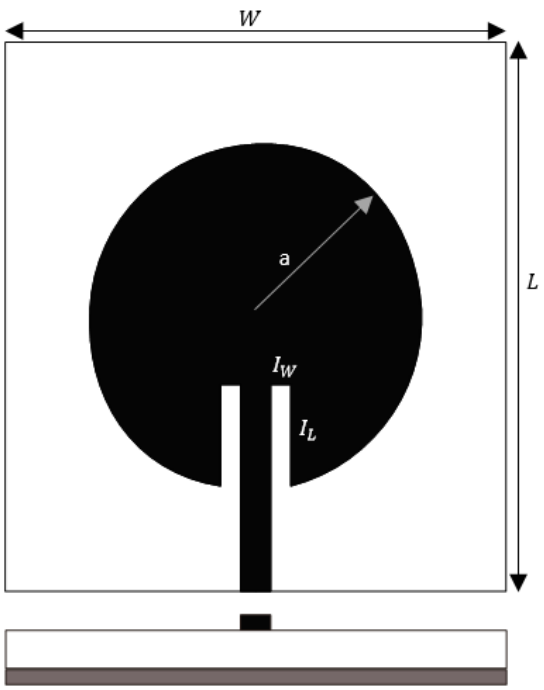

Figure 1. The conventional circular patch design

This antenna design considers the substrate of FR4 with a dielectric constant (ε_r) of 4.6. The substrate has 1.6 mm of the height (*h*) and 0.025 of the loss tangents (tan δ). Those parameters can determine the patch's actual radius (*a*) using cavity model formulation to resonate at 2.4 GHz [5]. The unit *a* in (1) must be in cm, while resonant frequency (f_r) in (2) is in Hz.

$$a = \frac{F}{\{1 + \frac{2h}{\pi \varepsilon_r F}[\ln\left(\frac{\pi F}{2h}\right) + 1.7726]\}^{1/2}} \quad (1)$$

where

$$F = \frac{8.791 \ x \ 10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

From (1) and (2), the obtained radius is 16.7 mm. The resonant frequency $(f_{rc})_{110}$ for the dominant TM_{110} can be expressed in (3), where v_0 is the speed of light in free space. A correction is introduced for circular patch design using an effective radius (a_ε) to replace the actual radius, as shown in (4).

$$(f_{rc})_{110} = \frac{1.8412 v_0}{2\pi a_\varepsilon \sqrt{\varepsilon_r}} \quad (3)$$

$$a_\varepsilon = \frac{8.791 \ x \ 10^9}{f_{rc}\sqrt{\varepsilon_r}} \quad (4)$$

Table 1. Conventional Circular Design Parameter

Parameters	Value (mm)
W	50
L	55
a	16.7
l_W	2
l_L	10
W_{feed}	3

By calculating the equations, the value of the effective patch radius is 17 mm. This size is the initial size for further steps to obtain the optimum result in resonant frequency after modifying the inset feed's length and width, where the input impedance is 50 Ω. Table 1 shows the parameters of the conventional design.

W_{feed} size that matches with impedance (Z_0) of 50 Ω can be calculated by determining B using (5) and then (6) [6][17]. Therefore, the obtained calculated of W_{feed} is 3 mm.

$$B = \frac{60\,\pi^2}{Z_0\sqrt{\varepsilon_r}} \tag{5}$$

$$Wfeed = \frac{2h}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\} \tag{6}$$

Figure 2 shows the conventional design's reflection factor's simulation results, where the expected resonant frequency at 2.4 GHz has a return loss value of -26.27 dB. Its bandwidth is 92.7 MHz, from 2360 MHz of a lower frequency to 2443.5 MHz of upper frequency. The gain from the simulation result is 0.64 dBi, respectively.

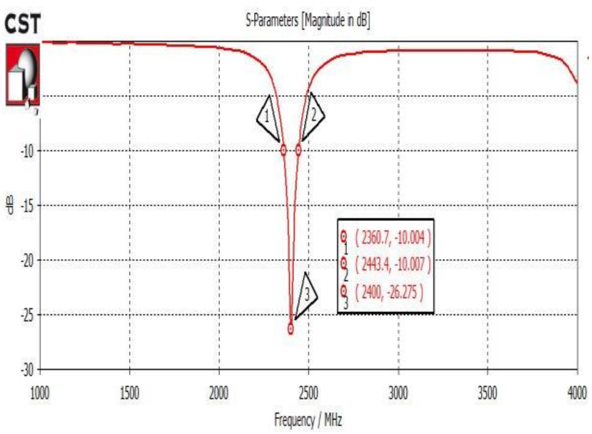

Figure 2. The simulated reflection factor of the conventional circular patch design

Defected Ground Structure (DGS) Design

The conventional antenna ground is modified with rectangular slotting, as shown in Figure 3, to attain optimum gain and bandwidth. This method is called a Defected Ground Structure (DGS). DGS is a microstrip antenna technique by defecting some structure on the ground surface of microstrip planar for enhancing gain and bandwidth purposes [18][19]. Slotting size is represented by G_W and G_L , which are 33 mm and 45.5 mm, respectively [20]. The design change influences the reflection factor at the center frequency, although it gave better bandwidth and gain. The matching problem's solution is to adjust the inset's dimension for the maximum reflection factor where l_L 8.8 mm is, and l_W I_w is 3.55 mm.

Figure 4 shows the effect of the modifying size G_L, where at a size range of 31 mm to 33 mm and the resonant frequency move around 2.4 GHz. Furthermore, from 33 mm to 35 mm, it went up to higher frequency. The best reflection factor (S_{11}) comes when the variable G_L is 33 mm.

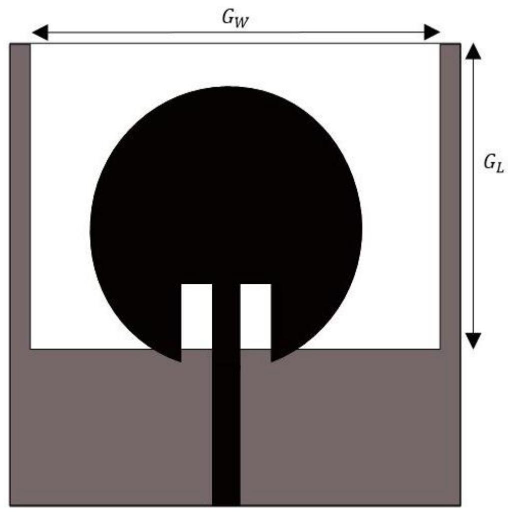

Figure 3. DGS circular patch design

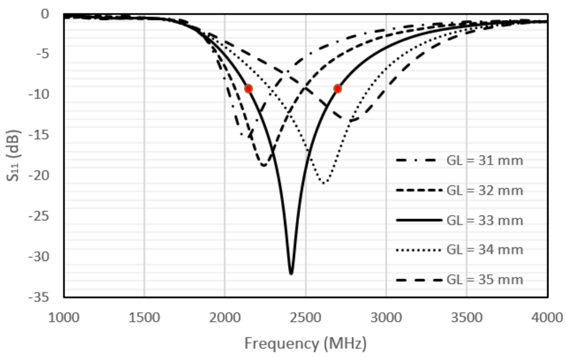

Figure 4. Iteration process of G_L

Figure 4 represents the iteration result of DGS design. It has 503.9 MHz of bandwidth, from 2163.1 MHz to 2667 MHz. At a frequency of 2.4 GHz, it obtains the reflection factor of -33.6 dB. Figure 5 shows the simulated gain result of DGS design that has 2.37 dBi. DGS design also has a reduced radius patch dimension, from 16.7 mm to 15.3 mm.

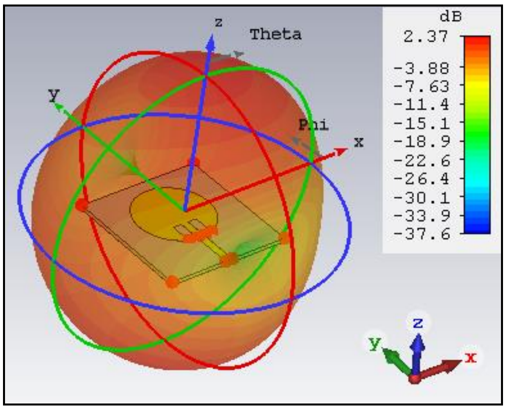

Figure 5. The simulated gain of DGS design

Defected Ground Structure and Horizontal Patch Gap (DGSHPG) Design

Based on the DGS design simulation result, this antenna will modify the bandwidth and gain improvement purposes. The method is to add a horizontal slit in the middle of the circular patch that separates both or like a gap. It is called the Horizontal Patch Gap (HPG). When HPG is combined with DGS design, it will be DGSHPG.

Figure 6 shows the geometry of the DGSHPG antenna, where the gap patch has a symbol *g*. Overall, the dimension circular patch and substrate using the HGP model is similar to DGS design.

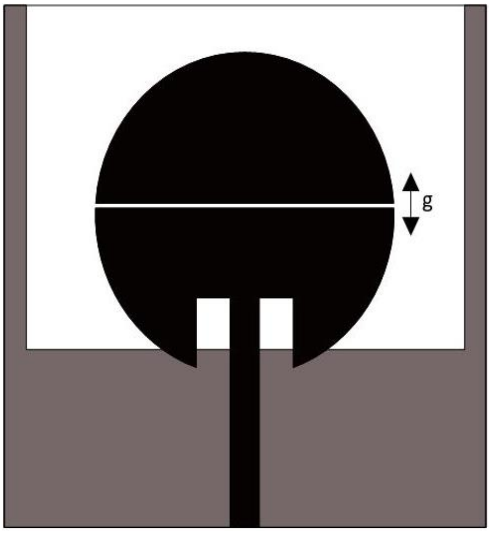

Figure 6. DGSHPG antenna design

Still, when the circular patch is modified with a slit, the center frequency moves because of the changes. The achieved optimum reflection factor of 2.4 GHz is obtained after iteration of the width and length inset feed.

Modifying gap size causes alteration of the reflection factor at 2.4 GHz, but the center frequency remains. The best result is when the gap is given at 0.5 mm, while under and over, its value obtained higher reflection factor, as shown in Figure 7. The size of the inset feed length and width is 7 mm and 3.55 mm, respectively. There is no change in the slotting ground dimension and radius of the patch.

Figure 7 shows the simulated reflection factor of the DGSHPG design when adjusting the dimension of the gap. It shows that at frequency 2.4 GHz, it obtains -53.3 dB of reflection factor. The bandwidth has achieved 764.4 MHz, from 2073.5 MHz to 2837.9 MHz. Figure 8 represents the gain of DGSHPG design from the far-field that has 2.8 dBi.

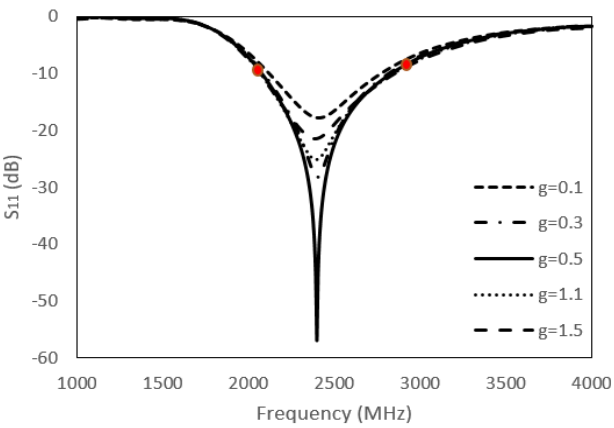

Figure 7. The simulated reflection factor of gap iteration

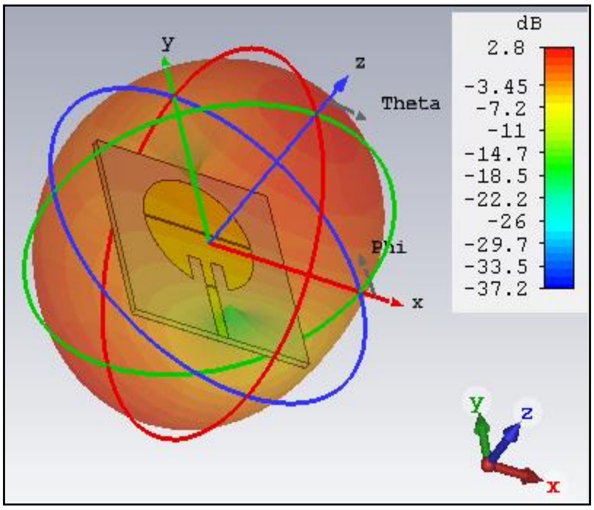

Figure 8. The simulated gain of DGSHPG design

RESULTS AND DISCUSSION

Three design stages deliver consideration that each design had experienced significant change, especially for bandwidth and gain improvement. The proposed design also generated optimum matching at the center frequency, as shown in Figure 9. In this case, the widening bandwidth can work for Wi-Fi and can clearly outcome to the 4G band or S-Band frequency. The increasing bandwidth is extremely caused by DGS design because the defect on the ground plane changed current distribution. This study's all design used a microstrip line as a planar transmission line with capacitance, inductance, and resistance structure. When the slot model includes the ground plane, the current distribution will be more effective [21]. That caused a significant change from the conventional design to DGS design, approximately more than 681.7 MHz of bandwidth increment. The proposed design (DGSHPG) produced more bandwidth, around 51%, compared to DGS design. This result happened because of the change of radiation mechanism influenced by the mutual coupling gap.

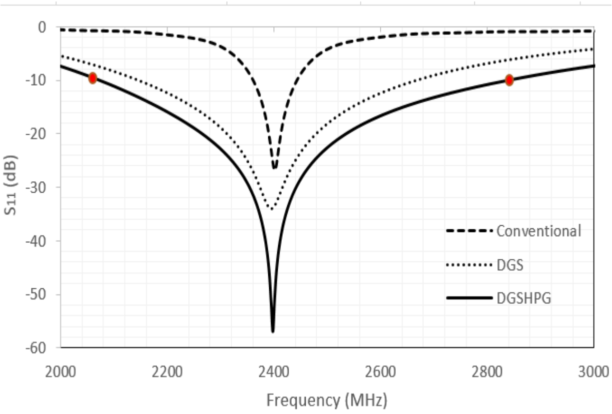

Figure 9. Comparison of simulated reflection factor from each design

Table 2. Performance Comparison of Each Design

Parameter	Conventional	DGS	DGSHPG
Lower Frequency	2360.7 MHz	2163.1 MHz	2073.5 MHz
Upper Frequency	2443.4 MHz	2667 MHz	2837.9 MHz
Bandwidth	82.7 MHz	503.9 MHz	764.4 MHz
Reflection factor 2.4 GHz	-26.27 dB	-33.6 dB	-53.3 dB
Gain	0.64 dBi	2.37 dBi	2.8 dBi
Patch Radius	16.7 mm	15.3 mm	15.3 mm

Table 2 shows a comparison of the simulated result of each design. Antenna design with a defective ground structure is combined with a horizontal gap demonstrated each parameter's best performance. DGSHPG achieved more matched in the reflection factor result, while its gain improved 0.43 dBi from DGS gain result. Another point that was achieved from the proposed design is reducing the circular patch compared to conventional design, from 16.7 mm to 15.3 mm. This reduction happened because of the need for impedance matching purposes. Some more increments in gain and bandwidth appear when the circular patch remains and impedance matching focus on inset feed or modification from the rectangular slot in the ground plane.

CONCLUSION

Antenna microstrip design using the defected ground and horizontal patch gap has shown improvement on more bandwidth and gain. Furthermore, DGSHPG design has an optimum result in impedance matching and gain and reduces the radius circular patch's dimension. This increasing bandwidth can be applied for the wideband and multiband frequency used for applications. Therefore, it can be concluded that this proposed design succeeded in enhancing antenna performance.

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