

3.5 GHz Rectangular Patch Microstrip Antenna with Defected Ground Structure for 5G

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ABSTRAK

Pada penelitian ini telah dilakukan perancangan dan implementasi antenna mikrostrip untuk aplikasi generasi kelima (5G) pada frekuensi 3.5 GHz. Parameter yang diinginkan berdasarkan pada posisi kebijakan publik Huawei, posisi kebijakan publik Qualcomm, dan artikel 3rd Generation Partnership Project (3GPP) Rel-15. Antena mikrostrip memiliki bandwidth yang sempit, oleh karena itu beberapa modifikasi digunakan, yaitu teknik proximity coupled dan defected ground structure (DGS). Tahap pertama adalah menghitung dimensi awal antenna, kemudian disimulasikan menggunakan HFSS Ansoft. Simulasi dimulai dari simulasi dimensi awal, menambahkan teknik proximity coupled, dan penerapan DGS hingga parameter antenna yang diinginkan tercapai. Aktivitas pengukuran dilakukan setelah simulasi dan optimasi telah selesai dikerjakan. Hasil dari pengukuran, gain bertambah menjadi 6.6 dB, bandwidth berkurang sebesar 65.2 MHz, Voltage Standing Wave Ratio (VSWR) dan return loss masing-masing 1.31 dan -17.436 dB.

Kata kunci: antenna mikrostrip, proximity coupled, DGS, 5G, 3.5 GHz

ABSTRACT

This research has performed the design and implementation of microstrip antenna for fifth generation (5G) application, at frequency 3.5 GHz. The desired parameters are based on Huawei public policy position, Qualcomm public policy position, and Rel-15 3rd Generation Partnership Project (3GPP) article. Since microstrip antenna has narrow bandwidth, some modification are conducted, namely proximity coupled feeding and defected ground structure (DGS). The first stage is calculating the initial dimension of the antenna, finally the antenna is simulated and optimized. The simulation starts from simulating the initial dimension, then applying the proximity coupled feeding, after that employing the DGS until the desired antenna is achieved. The final stage is fabricate the antenna based on simulation then measure it. The measurement results show that the gain is increased to 6.6 dB, the bandwidth is reduced by 65.2 MHz, the Voltage Standing Wave Ratio (VSWR) and return loss are 1.31 and -17.436 dB.

Keywords: microstrip antenna, proximity coupled, DGS, 5G, 3.5 GHz

1. INTRODUCTION

The fifth generation (5G) is the latest generation of cellular mobile communications. It succeeds the fourth generation (4G) with the Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMax), the third generation (3G) Universal Mobile Telecommunications System (UMTS) and second-generation (2G) Global System for Mobile communications (GSM) systems. 5G performance targets high data rate, reduced latency, energy saving, cost reduction, higher system capacity, and massive device connectivity. For instance, for the downlink (DL), the experienced data rate of up to 50 Mbps are expected outdoor and 1 Gbps indoor (5GLAN), and half of these values for the uplink (UL), with the target for user plane latency, should be 4 ms for UL, and 4 ms for DL **(3GPP, 2019)**. As 5G still on progress, there is no fix regulation in Indonesia, expected to be announced in 2020 or 2021 **(PERTIWI, 2018)**.

However, some institutions already have major parameters and specification requirement for this next-gen communication, such as 3rd Generation Partnership Project (3GPP) that has already finished the first phase. Also, some big companies have already published the specification for their future devices that will use 5G technology later, such as Huawei and Qualcomm, as pioneers for 5G patents in east and west respectively **(Qualcomm, 2017)**, **(Huawei, 2017)**. Figure 1 shows the frequency aspect for the 5G technology according to the 3GPP Rel-15 on 5G New Radio (NR) of two frequency ranges which are FR1 being sub-6 GHz range (450 - 6000 MHz) and FR2 being the millimeter wave (mmWave) range (24250 - 52600 MHz) **(3GPP, 2019)**.

Huawei also notes that, as the first steps, it highly recommend that the countries allocate 3300-3800 MHz or a portion of it and make it available for 5G with consistent timelines and regulatory frameworks, i.e., frequency arrangements and emission masks. It recommends that at least 100 MHz of contiguous bandwidth from this band allocated to each 5G network. The frequencies for 5G are divide into three groups, that is low frequencies, medium frequencies, and high frequencies **(Huawei, 2017)**. The design of microstrip patch antenna is a single-layer consist generally of four parts, i.e., the patch, ground plane, substrate, and feeding part. The physical size of a microstrip antenna is small. However, the electrical size measured in the wavelength is not so small. The most commonly employed microstrip antenna is a rectangular patch **(Paul & Sultan, 2013)**.

Microstrip patch antennas have more advantages and better prospects compared to the conventional antennas, such as lighter in weight, low in volume, cost, profile, and smaller in dimension, as well as ease of fabrication and conformity. Moreover, the microstrip patch antennas can provide frequency agility, broad bandwidth, feedline flexibility and beam scanning omnidirectional patterning **(Bisht, Saini, Prakash, & Nautiyal, 2014)**.

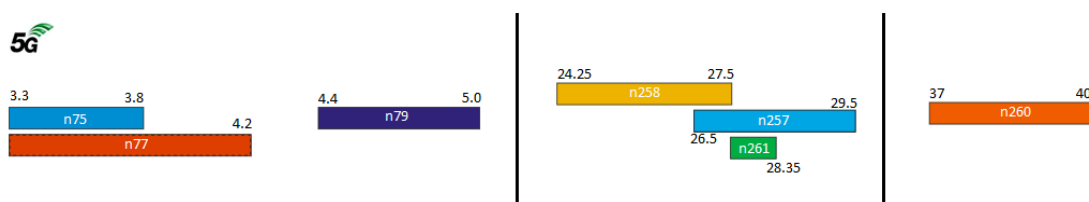


Figure 1. New NR Bands in FR1 and FR2 in Rel. 15 NR (3GPP, 2019)

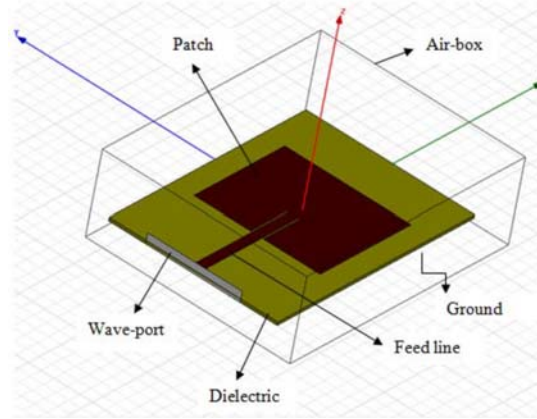


Figure 1. Structure of microstrip antenna (Mathur, Vats, & Agarwal, 2015)

There are also some disadvantages such as narrow bandwidth, low gain, generate unwanted radiation because of its unification technique and low efficiency. To overcome the disadvantages, we can use several approaches, such as changing the feedline and making a defected ground plane.

2. ANTENNA DESIGN

2.1 Calculation the Size of Patch

The formula used for designing the width of a patch antenna (W) are as **(Paul & Sultan, 2013)**

$$W = \frac{c}{2f\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

where f is the middle frequency, ϵ_r being material relative constants, c being the speed of light, and h being substrate thickness are 3500 MHz, 4.4, 3×10^8 m/s, and 1.6 mm, respectively. For $\frac{W}{h} > 1$, the effective dielectric constant (ϵ_{reff}) is defined by **(Paul & Sultan, 2013)**

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left(\frac{1}{\sqrt{1+12h/W}} \right) \quad (2)$$

The electrical length of a patch antenna is greater than the physical. This normalized extension in length is calculated using **(Paul & Sultan, 2013)**

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

The actual length of a patch antenna (L) calculated using **(Paul & Sultan, 2013)**

$$L = \frac{c}{2f\sqrt{\epsilon_{reff}}} - 2\Delta L \quad (4)$$

2.2 Determining the Size of Feedline

The feeding channel used in this paper has the impedance value equal to 50Ω calculated by

$$\frac{W_o}{h} = 5.7961(\epsilon_r^{-0.95}) \quad (5)$$

where W_o is the feedline width. From the Equation (1) - (5) the initial design of microstrip antenna single patch is shown by Table 1 as well as Figures 3 and 4. Table 1 shows the initial size of the antenna for the simulation. Figure 3 shows the substrate where the yellow area is the patch and the feedline. Figure 4 depicts the antenna ground plane and the antenna design.

Table 1. Microstrip Antenna Size for Simulation

The Size of Patch ($W \times L$)	26.08 x 18.98 mm
The Substrate Area ($W_s \times L_s$)	50 x 40 mm
The Size of Ground ($W_g \times L_g$)	50 x 40 mm
The Width of Feedline 50Ω (w_f)	2.27 mm
The Length of Feedline 50Ω (l_f)	20 mm

2.3 Initial Simulation Results

The calculation results of the above design using Ansoft HFSS 15.0 shown in Table 2 and Figures 5 and 6. As shown in Table 2, some of the desired parameters have not been achieving yet. The bandwidth and working frequency, which are still far from the desired, also needs to improve the other parameters. Figure 5 shows that the bandwidth achieved from the simulation is 0.1392 GHz or 139.2 MHz when the return loss is -16.32 dB. Furthermore, the working frequency at -10 dB is nowhere near 3.4 – 3.6 GHz. Figure 6 shows that the VSWR is 1.3603. It is required to modify the antenna dimension to achieve the desired parameters.

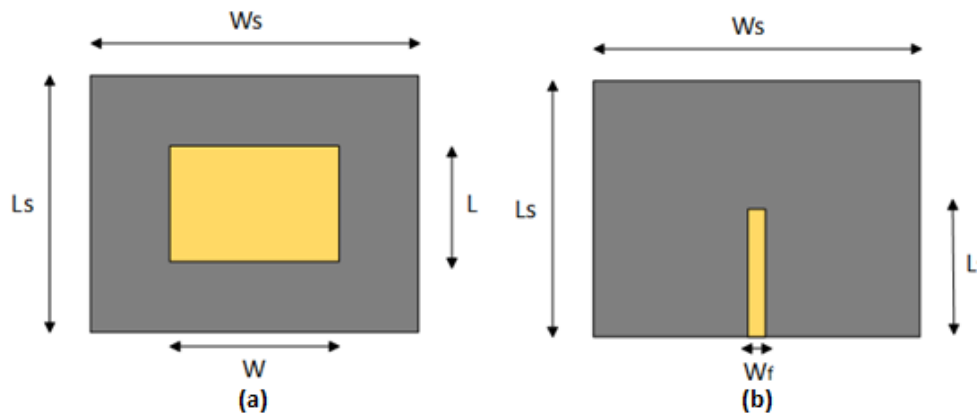


Figure 3. (a) Visualization of Antenna Patch and (b) Feedline

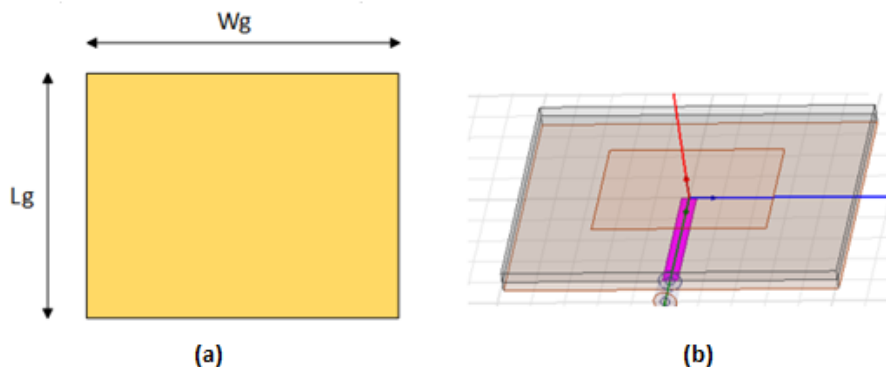


Figure 4. (a) Visualization of Antenna Ground and (b) Design on HFSS Ansoft 15

Table 2. Comparison of Simulation Results and Desired Parameters

Parameters	Simulation Result	Desired Parameters
Return Loss	-16.32 dB	≤ -10 dB
Working Frequency	3324.8 – 3464.0 MHz	3400 – 3600 MHz
Bandwidth	139.2 MHz	200 MHz
VSWR	1.3603	≤ 1.9
Gain	3.6544 dB	Maximum 15 dB

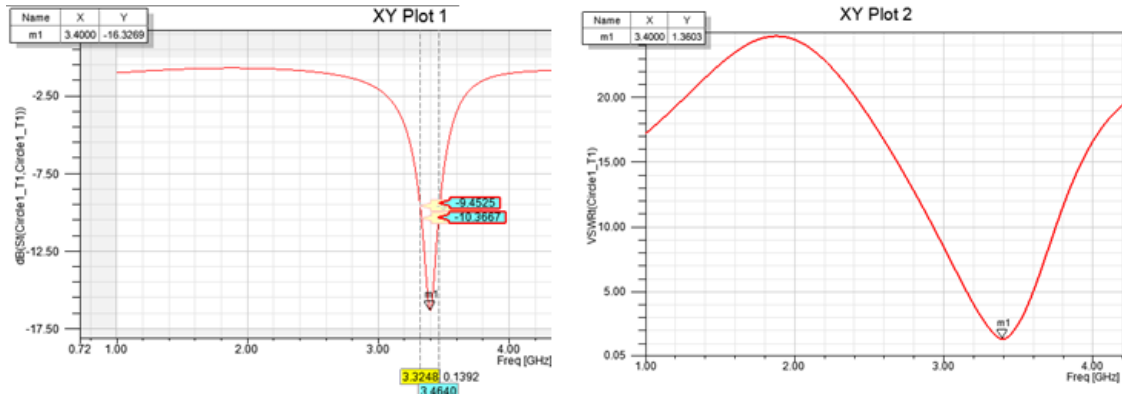


Figure 2. Simulation Results of the Working Frequency, Return Loss, and VSWR

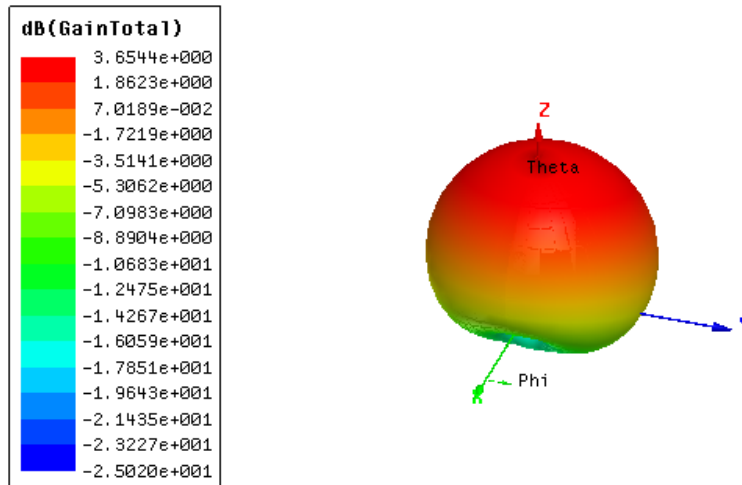


Figure 3. Simulation Results of Radiation Pattern and Gain

3. ANTENNA OPTIMIZATION AND MEASUREMENT RESULTS

3.1 Changing Patch Size & Feedline Length

For optimization, there are several modifications to the antenna dimensions. The first step is modifying the patch size. Table 3 shows the effects of changing the dimension of the patch. According to Table 3, the working frequency is close to the desired parameters. The second step is modifying the length of the feedline, shown in Table 4.

Table 3. Effects in Modifying the Dimension of the Patch

Patch Size (mm)	Return Loss (dB)	Working Frequency (MHz)	Bandwidth (MHz)	VSWR	Gain (dB)
W = 19.98 L = 26.08	-38.466	3159.5 – 3346.7	187.3	1.0515	2.714
W = 18 L = 26	-36.8453	3468.4 – 3658.3	189.9	1.0292	3.9812
W = 17.8 L = 26	- 32.43	3504.2 – 3692.8	188.6	1.067	4.0091
W = 18.8 L = 26	-44	3341.5 – 3532.6	191.1	1.0127	3.7851
W = 18.4 L = 26.2	-42.605	3400.9 – 3592.2	191.3	1.0155	3.996

Table 4. Effects in Modifying the Length of the Feedline

Feedline Length Size (mm)	Return Loss (dB)	Working Frequency (MHz)	Bandwidth (MHz)	VSWR	Gain (dB)
18	-28.2044	3357.9 – 3563.7	205.8	1.0809	3.9635
16	-33.6172	3322.5 – 3519.0	196.5	1.0426	3.9489
17	-31.4864	3336.2 – 3542.0	205.8	1.0548	3.9848
16.5	-32.811	3331.2 – 3537.9	206.7	1.0968	3.9526
16.3	-37.7945	3327.4 – 3430.8	203.4	1.0561	3.9725
17.4	-30.3301	3341.6 – 3547.5	205.9	1.0628	3.9359
17.5	-28.9186	3346.2 – 3553.0	206.8	1.0821	3.9789
17.8	-29.009	3351.2 – 3557.4	206.2	1.0735	3.9652
17.6	-29.5720	3350.4- 3556.4	206	1.0687	3.9808

3.2 Changing Substrate Size

From Table 4, the best length for the feedline is 17.5 mm. However, the working frequency is shifts a little. The next step is to reduce the overall dimension of the antenna, i.e., the ground plane and the substrate. The first dimension is 50 x 40 mm and then changed to 40 x 30 mm. The result is that it shifts the working frequency to 3327.3 – 3495.5 MHz, reduces the bandwidth to 169.2 MHz, return loss is – 13.3654 dB and VSWR is 1.55. It is because the dimension 40 x 30 mm leads the parameters changed too much. Then modify the dimension to 45 x 35 mm. Hence, Table 5 shows the results.

Table 5. Effects in Modifying the Substrate Dimension

Substrate Size (mm)	Return Loss (dB)	Working Frequency (MHz)	Bandwidth (MHz)	VSWR	Gain (dB)
45 x 35	-26.2841	3315.1 – 3536.3	221.2	1.13	3.6151

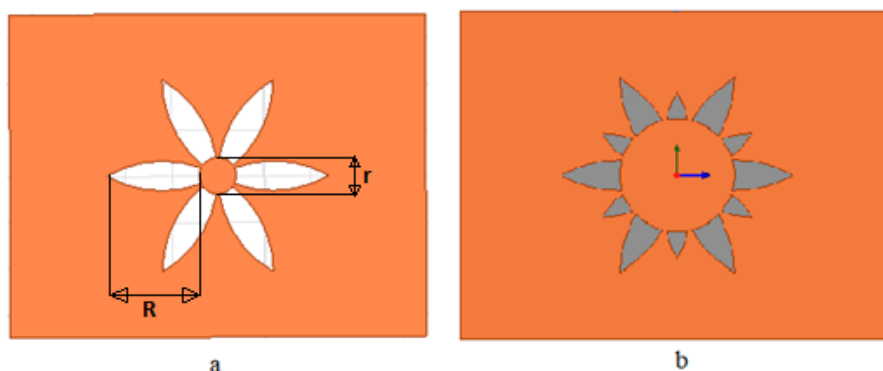
With this modification, we achieve the desired parameters. However, the working frequency still shifts. Hence, we modify the dimension of the patch and the length of the feedline. Table 6 shows the effects in modifying the patch dimension and the length of the feedline with 45 x 35 mm substrate. We achieve the desired working frequency when the patch dimension is 18 x 26.2 mm, and the length of the feedline is 15.2 mm.

Table 6. Effects in Modifying the Feedline and Patch Size

Patch & Feedline Size (mm)	Return Loss (dB)	Working Frequency (MHz)	Bandwidth (MHz)	VSWR	Gain (dB)
W = 18.2; L = 26.2; Lf = 15	-25.446	3358.2 – 3579	220.8	1.1129	3.6713
W = 18; L = 26.2; Lf = 15	-26.185	3388.2 – 3613.1	224.9	1.1032	3.7256
W = 18; L = 26.2; Lf = 15.2	-27.307	3388.2 – 3615.9	227.8	1.0931	3.7253

3.3 Applying DGS on Ground Plane

Implementing Defected Ground Structure (DGS) in microstrip patch results in improves the antenna bandwidth. Practically bandwidth obtained using DGS is up to 100 MHz Along with bandwidth, other parameters such as the uniform current distribution, beamwidth, return loss, reflection coefficient, VSWR, are also improved. The final step of the optimization is modifying the ground plane with DGS. Figure 7 shows the experimental DGS used in the simulation. It should note that Table 7 shows the effect of modifying the ground plane of the antenna.

**Figure 7. (a)(b) Experimental Defected Ground Structure (Weng, Guo, Shi, & Chen, 2008)****Table 7. Effects of Applying DGS on Ground Plane**

DGS (R) and (r)	Return Loss (dB)	Working Frequency (MHz)	Bandwidth (MHz)	VSWR	Gain (dB)
DGS (a) R = 9; r = 1	-25.9021	3252.6 – 3502.5	249.9	1.1209	3.3389
DGS (a) R = 9; r = 2	-28.8809	3294.7 – 3543.2	248.5	1.0859	3.4357
DGS (a) R = 12; r = 1	-25.3558	3204.8 – 3461.6	256.8	1.1141	3.1575
DGS (a) R = 12; r = 2	-23.0672	3133.2 – 3390.2	257	1.1543	2.8696
DGS (b) R = 9; r = 6	-39.4964	3362.3 – 3604.4	242	1.0214	3.6137
DGS (b) R = 9; r = 5.5	-36.5635	3323 – 3572.5	249.5	1.032	3.5060
DGS (b) R = 9; r = 7	-29.7706	3394.9 – 3628.1	233.2	1.0671	3.661

3.4 Antenna Final Size and Simulation Results

Based on Table 7, the last result is satisfied with the desired parameters. With the working frequency close to the desired parameters, it achieves better VSWR and positive gain. The following Table 8 as well as Figure 8 and Figure 9 are complete specifications and simulation results of Rectangular Patch Microstrip Antenna with Proximity Coupled Feeding Technique and Defected Ground Structure. Table 8 shows the final size of the antenna design that we will fabricate. Furthermore, Figures 8 shows the simulation result of the final design, i.e., the antenna working frequency, return loss, and VSWR. Next, Figures 9 shows the radiation pattern and gain of the antenna.

Table 8. Microstrip Antenna Final Design

Patch Size (W x L)	26.2 x 18 mm
Substrate Area (Wg x Lg)	45 x 35 mm
The Width of Feedline (Wf)	3.06 mm
The Length of Feedline (Lf)	17 mm
Inner radius of DGS	7 mm
Outer radius of DGS	9 mm

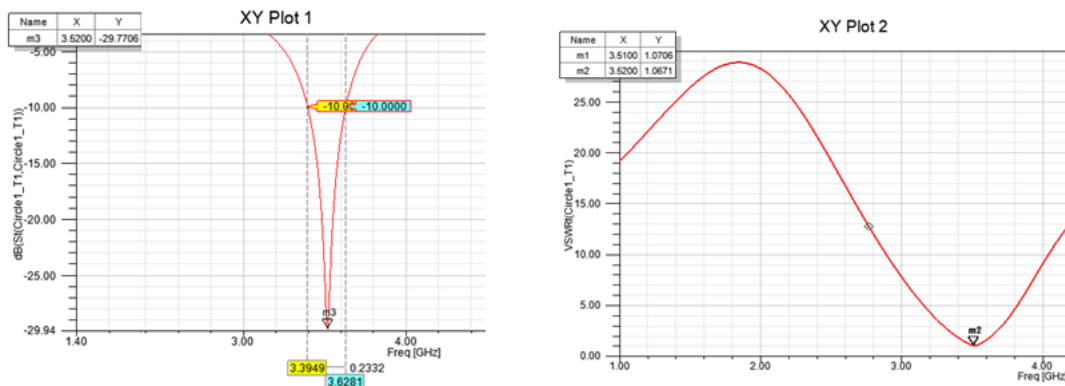


Figure 4. Final Simulation Results of the Working Frequency, Return Loss, and Voltage Standing Wave Ratio (VSWR)

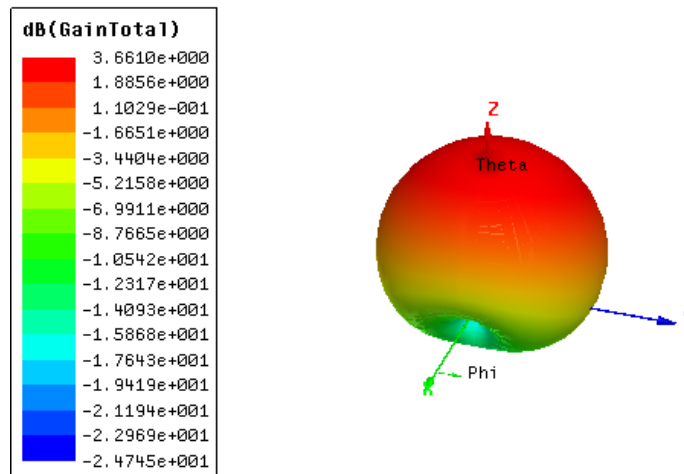


Figure 5. Final Simulation Results of Radiation Pattern and Gain

3.5 Fabricated Antenna

Based on the simulation design using HFSS Ansoft 15.0 software, the fabricated antenna shown in Figures 10 and 11. We fabricate the antenna on a double layer printed circuit board (PCB) that consists of two PCB. The first PCB or substrate etching for the patch of the antenna. And, the second substrate for the feedline and the ground plane of the antenna. Figures 10 and 11 show the etching result. Then, combine the two substrates, in this case, the first and second substrate with duct tape. On the feedline area, a connector soldered.



Figure 6. The First and Second Substrate of Antenna

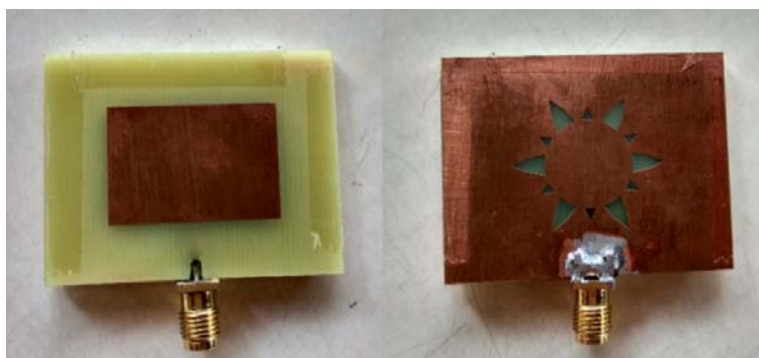


Figure 7. Antenna Front View and Back View

3.6 Antenna Measurement Results

Figures 12 and 13 show the antenna parameters that are measured. Figure 12.(a) shows the antenna working frequency and return loss results. While Figure 12.(b) shows the antenna VSWR results. The return loss is -17.436 dB, with the working frequency is at $3.417 - 3.585$ GHz. Hence, the bandwidth becomes 168 MHz, and the middle frequency is 3.5 GHz. The antenna VSWR measurement result are (1) the VSWR is of 1.919 for 3.417 GHz, (2) the VSWR is of 1.925 for 3.585 GHz, and (3) the VSWR is of 1.310 for 3.5 GHz. The antenna parameter uses the VSWR at the middle frequency.

The difference between the simulation and the measurement results are occurred by some several factors as follows. (1) The fabricated antenna shows that there is reduces in thickness. There is a trail of sandpapering the substrates, hence the thickness of the antenna is reduced. The change of thickness affects the bandwidth of the antenna. In addition, (2) the fabricated antenna manufactured conventionally by etching a double layer printed circuit board (PCB). This method also can cause the thickness of the substrates to decrease. Moreover, (3) when the two substrates combined, there is little gap near the connector.

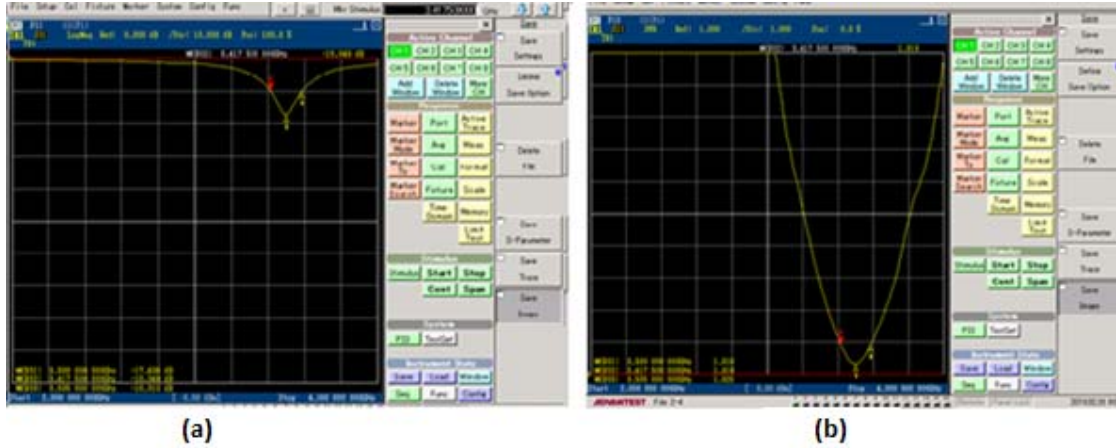


Figure 8. (a) Return Loss and Working Frequency Results; (b) VSWR Results

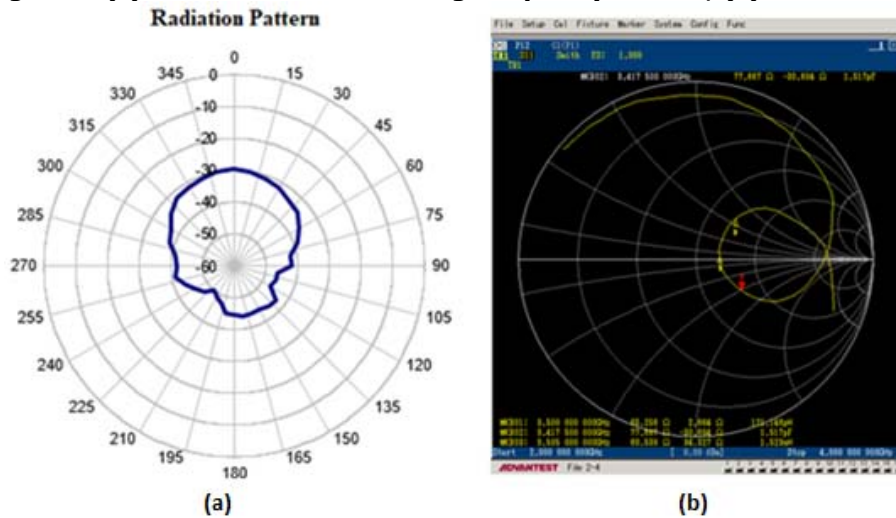


Figure 9. (a) Radiation Pattern; (b) Impedance Measurements Results

Figure 13.(a) shows the radiation pattern that achieved from measurement and processed with Microsoft Excel. While Figure 13.(b) shows the impedance of the antenna at 3.417, 3.5, and 3.585 GHz are 77.667, 65.256, and 68.538 Ω , respectively. The one used as the input impedance of the antenna is the impedance at the middle frequency. The impedance of the antenna at 3.417, 3.5, and 3.585 GHz are 77.667, 65.256, and 68.538 Ω , respectively. It should note that the one used as the input impedance of the antenna is the impedance at the middle frequency.

To measure the magnitude of the gain on the antenna, we can use the equation expressed as

$$G = P_1 - P_2 + G_{Reff} \quad (6)$$

where P_1 is the gain value of two identical horn antenna, P_2 is the gain value when microstrip antenna tested as a receiver, and G_{Reff} is the gain value of the reference antenna. Referring to Equation (6) with P_1 of -33 dB, the value of P_2 of -29.51 dB and the reference antenna gain value of 10.1 dB, the antenna gain value is 6.61 dB. Table 9 shows the final simulation and measurement results. It shows the simulation and measurement results are not in accordance, but both still satisfy the desired parameters.

Table 9. Simulation and Measurement Results

Parameter	Simulation	Measurement
Return Loss (dB)	-29.77	-17.436
Working Frequency (GHz)	3.395 – 3.628	3.417 – 3.585
Bandwidth (MHz)	233.2	168
VSWR	1.0671	1.31
Input Impedance (Ω)	50	65.256
Gain (dB)	3.661	6.61
Radiation Pattern	Directional	Directional
Polarization	Linear	Linear

4. CONCLUSION

There are some differences between the simulation and the measurement results, but the parameters are considered well enough, as it is satisfied the desired parameters. It is because the bandwidth decreased by a significant amount. The results in this research are that the VSWR increased by 0.242, the impedance increased by 15.256 Ω , the gain increased by 3 dB, and the return loss changed to -17.436 dB. The VSWR, return loss, and gain are satisfied the desired parameters. Also, the bandwidth satisfies both the public position of Huawei and Qualcomm. Huawei advises that the bandwidth for 5G at least 100 MHz. While, Qualcomm advises that for mid-band 5G, the bandwidth is 150 MHz. Finally, the simulation and the measurement results show that the antenna is in accordance with the desired parameters. It is expected that hopefully, the antenna is useful for 5G applications.

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