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DESIGN OF RECTANGULAR PATCH MICROSTRIP ANTENNA WITH DEFECTED GROUND STRUCTURE METHOD AT 3.5 GHZ FREQUENCY FOR 5G TECHNOLOGY

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Abstract--**5G technology is currently developing rapidly in various countries. 5G technology has three sub-frequencies: low band, midband and high band. Midband frequencies in Indonesia are between 2.6 GHz and 3.5 GHz. In order for 5G technology is able to be used in Indonesia, it needs an antenna that can work at 3.5 GHz and has a wide bandwidth. Microstrip antenna is a simple and efficient antenna. However, microstrip antenna has minimal bandwidth. To overcome this, certain methods are needed, one of which is the defected ground structure (DGS) method. The initial design of the antenna has dimensions according to the results of the calculation formula. Then optimization is carried out by reducing the dimensions of the antenna components. After that, the DGS method is applied to widen the bandwidth. The initial design of the single-patch antenna before using the DGS method has a return loss value of -19.96 dB, VSWR 1.22, with a gain value of 3.812 dB and bandwidth 105.1 MHz. The simulation results of the antenna using DGS have a return loss value of -39.76 dB, VSWR of 1.02, with a gain value 3.16 dB and a bandwidth of 158.4 MHz. These results prove that the use of the DGS method can increase bandwidth.**

Keywords: **5G; Defected Ground Structure; Microstrip; Midband.**

I. INTRODUCTION

Currently cellular technology has entered its fifth generation (5G). According to the International Telecommunication Union (ITU), the 5G technology standard has a data rate of 20 Gbps on the downlink and 10 Gbps on the uplink with a latency of less than 1 ms [1], [2]. 5G technology has three sub-frequencies, there are low band, midband and high band. Midband frequencies have the advantage of data rates over low band, but with wider coverage than high band. Midband frequencies is appropriate for Enhanced Mobile Broadband (eMBB) use case. EMBB is one of the use cases for 5G technology which supports user to user communication. In Indonesia 2.6 GHz and 3.5 GHz are chosen for midband frequency of 5G [3], [4]. The 3.5 GHz has advantage of wider bandwidth that can increase data rates and served number of users that can be served.

In cellular communication systems, antenna devices are needed to send and receive electromagnetic signals. Microstrip antenna is one of the microwave antennas with the characteristics of being simple, efficient and easy to fabricate at an affordable cost. However, microstrip antennas have minimal bandwidth, but there are methods that can overcome these deficiencies. Methods that can be used to widen the bandwidth of microstrip antennas include cutting patches (slots) and cutting ground or Defected Ground Structure (DGS) [5], [6]. The rectangular patch shape on a microstrip antenna is one of the most widely used patch shapes because it is simple and easy to integrate.

Increasing bandwidth in 5G communication antenna at frequency 3.5 GHz has been carried out [6]. It shows that left handed material (LHM) method in triangular patch antenna could increase the bandwidth of antenna. This method has significant bandwidth improvement, 294 MHz larger bandwidth than before. An antenna 1 x 12 array for 5G communication has been done in [7]. It shows that center-fed series antenna has increased bandwith by 20% and a maximum gain of 19 dBi is achieved. In research [8] a Wi-Fi

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antenna simulation was simulated at 2.45 GHz. The DGS method could increase bandwidth by 67.5 MHz. The substrate type in the previous antenna design is made by using RT Duroid 5880, but in Indonesia it is limited and more costly. In Indonesia, FR-4 type substrates are more often found, and the reasons is that it has lower cost. So in this research, a 5G antenna simulation will be carried out using an FR-4 substrate at a frequency of 3.5 GHz using the DGS method.

II. METHOD

This research started with a lot of literature reviews to determine antenna specifications. Thereafter, a simulation was created using Ansoft HFSS 13.0 software. After the simulation is finished, it will be seen whether the results meet the specifications or not. After that, analysis and conclusions are drawn. The flowchart for this research can be seen in Fig. 1. Antenna parameter specifications are required before calculations are carried out to determine antenna dimensions. Antenna parameter specifications can be seen in Table 1.

A. 5G Technology

5G technology marketing targets simple and cost-effective implementations on the spectrum. Frequency rearrangement (reframing frequency) in this spectrum is an advantage of 5G implementation. Therefore, the spectrum of previous mobile communication technologies (2G, 3G, and 4G) will be used for 5G. Meanwhile, in previous cellular communications, mmwave frequency had never been used due to technological limitations, so its use was one of the new things in cellular technology.

3GPP has defined the frequency ranges on 5G:

1. Frequency range 1 (450 MHz to 6 GHz)
2. Frequency range 2 (24.25 GHz to 52.60 GHz)

The determination of this frequency range allows for different requirements in each range. For example, the separation for each frequency range is based on sensitivity and out-of-band emission. This requirement takes into account the UE (user equipment) and different network implementations depending on the frequency range. For example, the UE with a frequency range of 2 will likely be equipped with an antenna that has beamforming capabilities. In contrast, the UE with a frequency range of 1 tends to be equipped with a small number of antenna elements distributed around the device [7].

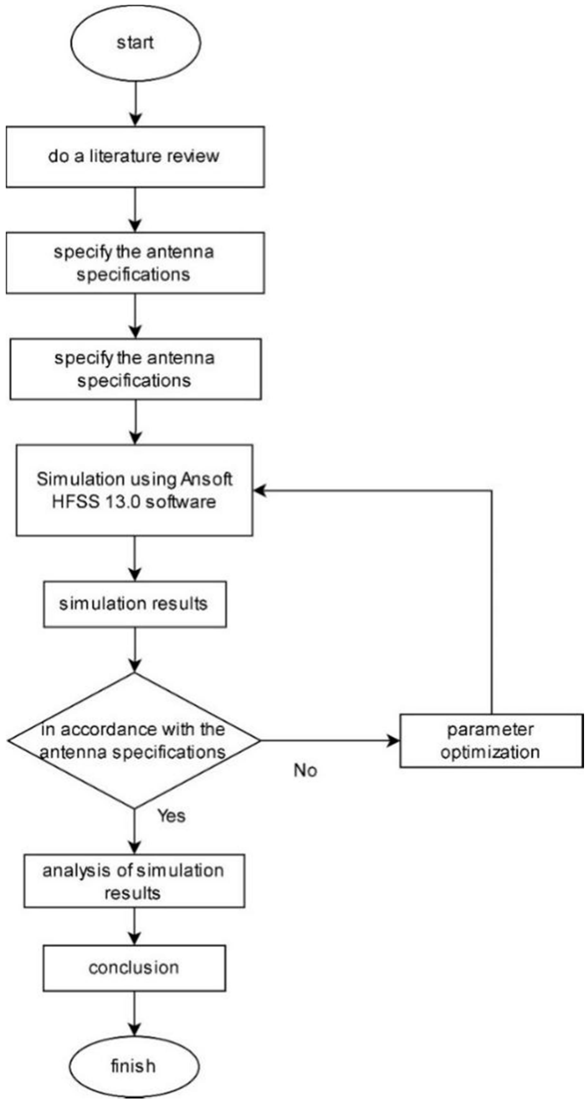

Fig. 1. Research flowchart

TABLE I
Antenna specification

Parameter	Specification
Frequency	3,5 GHz
Return loss	≤-10 dB
VSWR	≤ 2
Bandwidth	≥ 100 MHz
Gain	≥ 3 dB
Input impedance	50 Ω

B. Microstrip Antenna

Fig. 2 shows the arrangement of the microstrip antenna. In general, a microstrip antenna consists of three parts, namely the transmitting element (antenna patch), the transmission line, and the ground plane, which can be printed on one or

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more dielectric substrates. This can be seen in Fig. 2, where the parameter h is the thickness of the substrate, the loss tangent (tan δ) is the dielectric loss, and εr is the dielectric constant of the substrate [5].

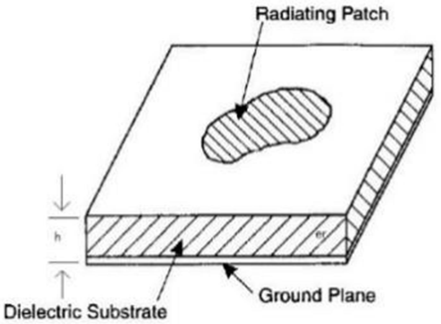

Fig. 2. Microstrip antenna arrangement [8]

C. Antenna Dimension Calculation

To make an antenna design, it is necessary to know the size of the antenna by determining the dimensions of the antenna. The formula for calculating the dimensions of a rectangular patch microstrip antenna is as follows [9], [10]:

1. Width *patch* (W_p)

$$W_p = \frac{c}{2f_c}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

2. Length *patch*

   The patch length is calculated using the equation:

   a. Effective dielectric constant value (ε_{eff}):

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\ s/W_p}}\right) \quad (2)$$

   b. Edge field effects on patches (ΔL):

$$\Delta L = 0{,}412\ h_s \frac{(\varepsilon_{eff}+0{,}3)\left(\frac{W_p}{h_s}+0{,}264\right)}{(\varepsilon_{eff}-0{,}258)\left(\frac{W_p}{h_s}+0{,}8\right)} \quad (3)$$

   c. Effective patch length (L_{eff}) and Patch Length (L_p):

$$L_{eff} = L_p + 2\Delta L \text{ atau } L_{eff} = \frac{c}{2f_c\sqrt{\varepsilon_{eff}}} \quad (4)$$

3. Substrate and ground plane width (W_s):

$$W_s = W_g \geq 6h + W_p \quad (5)$$

4. Substrate and ground plane length (L_s):

$$L_s = L_g \geq 6h + L_p \quad (6)$$

5. Calculation of the length and width of strip line:

$$L_f = \frac{c}{4f\sqrt{\varepsilon_{eff}}} \quad (7)$$

$$W_f = \frac{2h_s}{\pi}\left[\begin{array}{c} B-1-\ln(2B-1)+ \\ \frac{\varepsilon_r-1}{2\varepsilon_r}\left(\ln(B-1)+0{,}39-\frac{0{,}61}{\varepsilon_r}\right)\end{array}\right] \quad (8)$$

When,

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (9)$$

The required antenna dimensions include the patch, ground plane, substrate, and supply channel. This study discusses the microstrip patch rectangular antenna with the DGS method at a frequency of 3.5 GHz. By using (1) to (9), we can know the dimensions of the antenna. In Table II, it can be seen the change in dimensions of each antenna component, which includes patch width, patch length, stripline width, stripline length, substrate width, and substrate length. Beside that, there is a reduction in the dimensions of the antenna components.

TABLE II
Antenna dimension after optimization

Component	Component symbol	Dimension (mm)	
		Before optimization	After optimization
Width patch	Wp	26,082	25,434
Length patch	Lp	20,165	19,665
Width stripline	Wf	3,059	1,5
Length stripline	Lf	10,216	9,75
Width substrate	Ws	52,164	50,868
Length substrate	Ls	40,33	39,33

In Fig.3 and Fig.4, there are images of a single patch antenna after optimizing the dimensions of the patch, stripline, substrate, and ground. The appearance of the ground still has the same dimensions as the substrate.

D. Defected Ground Structure (DGS)

In addition to the narrow bandwidth of a microstrip antenna, the existence of surface waves, which cause a decrease in antenna efficiency, is also a drawback of using a microstrip antenna. To overcome these deficiencies, the DGS (Defected Ground Structure) method can be used [6]. Defected ground structure (DGS) is a method of trimming

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or removing some of the ground components so as to suppress surface waves, increase the bandwidth of the antenna, and improve the value of return loss [11].

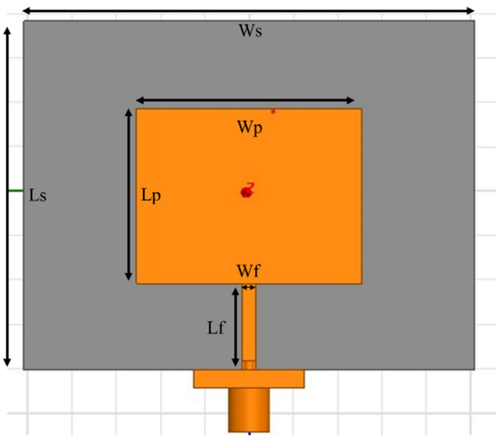

Fig. 3. The front of the single patch antenna design after optimization

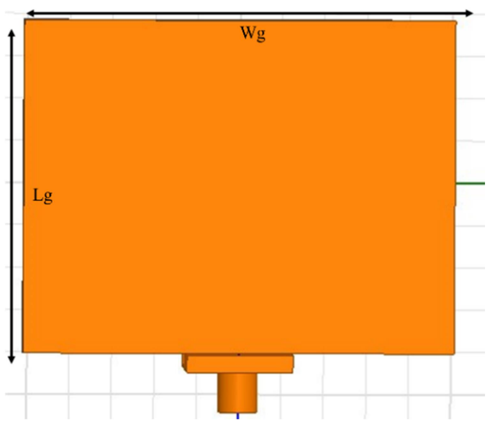

Fig. 4. The rear of the single patch antenna design after optimization

E. Bandwidth

Bandwidth is the working frequency range of the antenna. The bandwidth value can be known if the lower and upper frequency values of the antenna are known. The lower frequency is the initial frequency value of the antenna's working frequency, while the upper frequency is the final frequency value of the antenna's working frequency. However, it is also agreed in the design that the upper frequency or lower frequency is the working frequency of the antenna. There is a formula that can be used to determine the bandwidth of an antenna:

$$BW = \frac{f_2 - f_1}{f_c} \times 100\% \qquad (10)$$

Where:
BW : bandwidth (Hz)
f_2 : upper frequency (Hz)
f_1 : lower frequency (Hz)
f_c : center frequency (Hz)

Antenna bandwidth is usually expressed as a percentage of bandwidth because it is more constant with frequency. In addition, the bandwidth of microstrip antennas can also be represented as the frequency range between increasing the VSWR value from one to a tolerable value [5].

III. RESULT AND DISCUSSION

In this study, the ground was cut in two ways to apply the DGS method, namely vertically and horizontally. After that, a comparison of the parameter results is carried out, and the best result is selected by prioritizing the value of the bandwidth parameter and return loss.

The initial ground dimensions before cutting were 50.868 mm as ground width and 39.33 mm as ground length. The initial ground dimension is the dimension obtained after optimizing the patch and stripline to get the center frequency value and return loss according to specifications, namely ≤-10 dB.

There were two trials of cutting the ground vertically and horizontally, respectively. On the ground, dimensions of 24 × 39.33 mm and 25.434 × 39.33 mm are vertical DGS. While on the ground, dimensions of 50.868 × 29.415 mm and 50.868 × 38.33 mm are horizontal DGS. In Fig. 5 and 6, changes in the ground dimension affect the center frequency, return loss, and VSWR. Vertical cutting of the ground has a lower return loss value than horizontal cutting of the ground. In addition, the value of the gain parameter can be seen in Fig. 7 with the highest gain value being ground with initial dimensions of 50.868 mm × 39.33 mm.

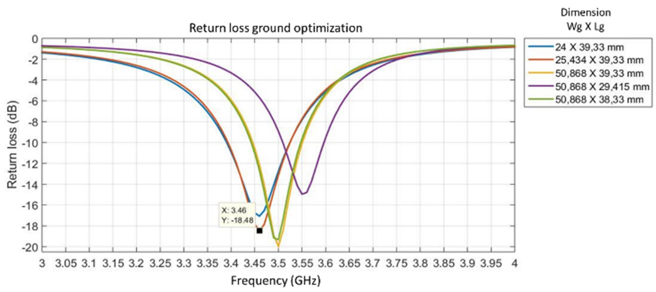

Fig. 5. Comparison graph of return loss parameters on ground optimization

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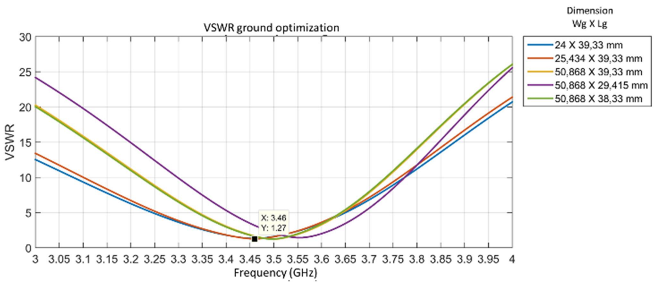

Fig. 6. VSWR parameter comparison graph on ground optimization

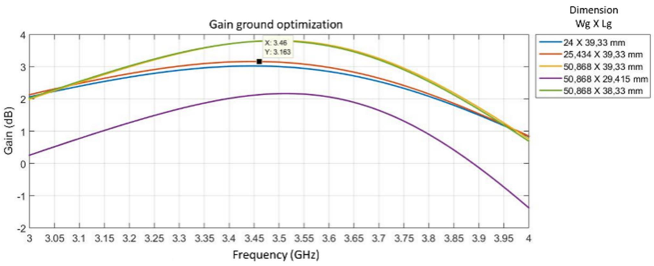

Fig. 7. Gain parameter comparison graph on ground optimization

It can be seen in Table III that the third row, which is the initial ground dimension, has the best value on the return loss, VSWR, and gain parameters. But in terms of bandwidth parameters, ground with dimensions of 24 × 39.33 mm is the best. If a comparison is made of the return loss values between the first and second rows, which both have an increase in bandwidth, the ground with dimensions of 25.434 × 39.33 mm is the main choice for applying the DGS method because it has a better return loss value.

TABLE III
Comparison of ground optimization parameter results

Width *ground* (mm)		24	25,434	50,868	50,868	50,868
Length *ground* (mm)		39,33	39,33	39,33	29,415	38,33
Return loss (dB)		-17,06	-18,48	-19,96	-14,96	-19,32
VSWR		1,326	1,27	1,223	1,435	1,242
Gain (dB)		3,023	3,163	3,812	2,151	3,8
Freq (GHz)	**Lower**	3,391	3,393	3,446	3,51	3,443
	Center	3,46	3,46	3,5	3,55	3,5
	Upper	3,524	3,524	3,551	3,596	3,547
Bandwidth (MHz)		133	130,7	105,1	86,2	104,6

To determine the width of the bandwidth, it is necessary to know the lower and upper frequencies, which can be determined at -10 dB in the return loss parameter. Bandwidth can be calculated using equation 2.10; the following uses ground with dimensions of 24 × 39.33 mm as an example of calculating bandwidth:

$$\mathrm{BW} = \frac{3{,}5238 - 3{,}391}{3{,}5} \times 100\% = 3{,}8\ \% \ (133\ \mathrm{MHz})$$

Based on the optimization carried out, vertical DGS is effective in reducing the value of return loss and resulting in a wider bandwidth. However, with the addition of the DGS method, the center frequency is reduced or shifted to the left, so it is necessary to change the patch dimensions to get the center frequency according to the specifications. In addition, changes to the dimensions of the stripline can also be made so that the maximum return loss parameter results are obtained. In Fig. 8 and Fig. 9, the antenna single patch is designed after applying the DGS method.

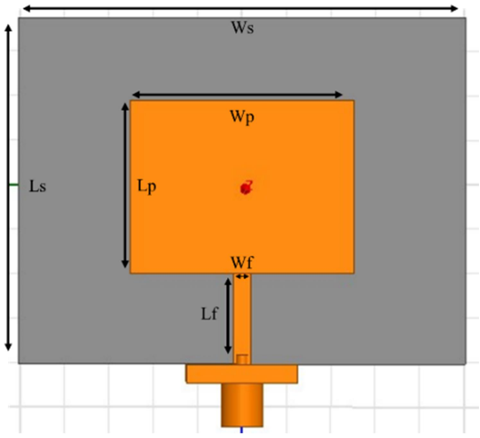

Fig. 8. The front of the single patch antenna design after applying the DGS method

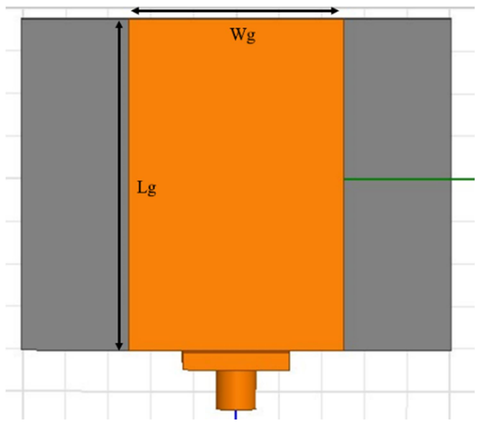

Fig. 9. The rear of the single patch antenna design after applying the DGS method

After optimization, the dimensions of the patch have decreased. The difference can be seen in Table IV. This is because when the ground is cut vertically, the frequency will decrease, and a

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reduction in patch dimensions is required in order to get the desired frequency back. After DGS was applied, the width of the ground became the same as the width of the patch. The stripline dimension was added, and this affects the value of return loss and VSWR. However, with the implementation of the DGS method, the value of the gain parameter was reduced by 0.648 dB to 3.164 dB. A comparison of the results of the two parameters can be seen in Table V, which contains the parameters return loss, VSWR, gain, frequency, and bandwidth.

TABLE IV
Comparison of antenna dimensions before and after using DGS

Component	Component symbol	Dimension (mm)	
		Without DGS	With DGS
Width patch	Wp	25,434	25,159
Length patch	Lp	19,665	19,453
Width stripline	Wf	1,5	2
Length stripline	Lf	9,75	10,216
Width substrate	Ws	50,868	25,159
Length substrate	Ls	39,33	39,906

TABLE V
Comparison of parameter results before and after using DGS

Antenna single patch		Without DGS	With DGS
Return loss (dB)		-19,963	-39,763
VSWR		1,223	1,021
Gain (dB)		3,812	3,164
Freq(GHz)	**Lower**	3,4456	3,417
	Center	3,5	3,5
	Upper	3,5507	3,5754
Bandwidth (MHz)		105,1	158,4

IV. CONCLUSION

The design and simulation of a single-patch antenna using the DGS method at a frequency of 3.5 GHz can increase the bandwidth by 53 MHz. The dimensions of the stripline also affect the value of the antenna's return loss and VSWR. However, applying the DGS method can reduce the antenna gain. The width of the ground in the vertical DGS method is the same as the patch width, so that the best results are obtained from the return loss and VSWR parameters.

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