Designing Franklin's Microstrip Antenna with Defected Ground Structure at MMwave Frequency

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Abstract —The development of telecommunication technology is very rapid at this time has entered into 4G technology. Soon, the 5G technology has a fast data access speed of at least 1 Gbps. To support 5G technology is carried out in-depth research, especially in 5G antennas. This study aims to increase the bandwidth of Franklin's five array microstrip antennas using the DGS (Defected Ground Structure) method for 5G antenna applications at an operating frequency of 28 GHz. The research was conducted by doing rectangular defects in the ground field. This research produced an enhanced bandwidth by 1.707 GHz from 1.196 GHz without DGS (Defected Ground Structure) to 2.9 GHz with DGS (Defected Ground Structure). It means a bandwidth enhancement of 142.47%. At the same time, the design achieved a gain enhancement of 141.7 %. Franklin's microstrip antenna output with DGS (Defected Ground Structure) method from the research simulation results are the bandwidth of 2.9 GHz, reflection factor of -52.95 dB, and Gain 11.80 dB. In comparison, the results of antenna measurements that have been fabricated produce bandwidth of 2 GHz, reflection factor -27.72 dB on frequency 26.6 GHz. The deviation between the simulation and measurement may result in inaccuracies during the fabrication process.

Index Terms—Antenna microstrip, DGS (Defected Ground Structure), franklin microstrip, roger duroid 4003

I. INTRODUCTION

5G wireless data communication will be realized for commercially in 2020 [1]. The fifth-generation technology offers various advantages, including ubiquitous connectivity, extremely low latency, and very high-speed data transfer [2]. The FCC (Federal Communication Commission) proposes for 5G wireless broadband frequencies started from 3.5-6 GHz [3], 27-40 GHz, and 64-71 GHz bands [4].

On the other hand, the availability of a very wide bandwidth from 30 to 300 GHz in mm-Wave region has been proposed to be a part of the 5G mobile network to provide multi-gigabit communication services [5]. Wireless communication is one of the frontier technologies that has been widely used in modern applications. It was the modern technologies that have evolved in a very fast way. One of the technologies that have wireless applications nowadays was 5G mobile communication. 5G wireless mobile communication that employs millimeter wave offers high-speed wireless information transfer [6]. Because of this wireless information transfer feature, these technologies have been developed into a different field such as the Internet of Things (IoT), Smart Cities, etc. The use of millimeter-wave frequency has an impact on a decrease of the mobile phone antenna dimensions. The conventional antennas were replaced with a microstrip antenna structure. The microstrip patch antenna has emerged as the best candidate for mobile communication devices with its small and lightweight. Problems arise because of the nature of its application, a 5G application that employs a millimeter wave has a very wide frequency spectrum from 30 GHz to 300 GHz. To solve this problem, we proposed a tri-band microstrip antenna design to be used in the millimeter-wave frequency for targetting 5G application [7].

Antenna microstrip is one type of antenna that can meet this need. Antenna microstrip has several advantages compared to other types of antennas. Its thin and small shape has lightweight, is easy to fabricate, can evoke linear polarization and circular polarization only by using a simple design, easy to integrate with other electronic devices, and relatively low prices. One way to suppress surface waves is to use the defected ground structure technique, which is one of the development techniques of EBG to suppress surface waves that are often used on microstrip antennas [8]. The defected ground structure (DGS) techniques are an effective technology for mutual coupling reduction [9]. However, the inherent drawback of DGS, the unwanted backward radiation, results in constrained applications. The resonators applied in the antenna array, which can change the coupling mode or the direction of the coupling field, are also a typical mutual coupling reduction method. It cannot be overlooked that the resonator will degrade the polarization purity of the antenna array [10]-[11]. In recent years there has been an increase in the use of the DGS method for enhancing microstrip antennas [12].

The widening antenna bandwidth caused the main radiance to decrease from 10 dBi to 6.51 dBi, and the increase in HPBW (Half Power Beamwidth) value from 18.2° rose to 38.8°. The Franklin concept was geometrically modified to convert conventional narrowband antennas into wideband antenna array models. Antenna making is done by printing inkjet on thin PET film material to achieve suitability and flexibility. Measurements show that the array designed includes 24.6–30 GHz [13].

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In this study, the author modified the antenna by adding DGS (Defected Ground Structure) method on the Franklin microstrip antenna array to produce expected antenna specifications. Besides, the authors replaced substrate materials using Roger Duroid RO4003C, which has a high permittivity value above previous research.

II. The Proposed Antenna Structure

This chapter will discuss the implementation of simulation to produce antennas according to the specifications desired. Antenna design consists of two steps, specify the antenna specifications and calculation the antenna dimension.

A. *Antenna Specifications*

Here, the desired antenna specifications are determined, such as substrate selection, operating frequency, gain, working frequency limit, bandwidth, and antenna radiation pattern. In the process of designing antennas, it is necessary to determine the specifications to be achieved. This study will develop a Franklin microstrip antenna with DGS (Defected Ground Structure) method with the antenna specifications as given in Table I.

TABLE I: SPESIFICATION OF ANTENNA

No	Parameter & Material	Expected Value
1	Substrate Material	Roger 4003c
2	Method	Mikrostrip with DGS method
3	Working Frequency	28 GHz
4	Permittivity (εr)	3.55
5	thickness (h)	0.813 mm
6	Copper Thickness	0.035 mm
7	Bandwidth	> 1 GHz
8	Frequency Limit	26 GHz – 30 GHz
9	*Reflection factor*	< -10 dB
10	Impedance Transmission Line	< 50 Ω
11	Parallel Impedance 1	35 Ω
12	Parallel Impedance 2	70.71 Ω
13	Radiation Pattern	Omnidirectional
14	Gain	≥ 10 dB

B. *Antenna Dimension Calculation*

After determining the antenna specifications, we now calculate the transmission line width, transmit channel length, patch width, patch length, arm width, slot width, ground length, and ground width.

Substrates are dielectric materials that have a constant value of dielectric (εr), dielectric loss tangent (tan δ), and a certain thickness (h). These three values affect the working frequency, bandwidth, and efficiency of the designed antenna—the greater the value of dielectric constants, the smaller the patch size, reducing the radiation area. Table II gives the complete information according to the substrates used in this research.

TABLE II: SPECIFICATIONS OF SUBSTRATES USED

No	Substrate Type	Value
1	Substrate Material	Roger 4003c
2	Dielectric constants (εr)	3.55
3	Dielectric loss tangent (tan δ)	0.0027
4	Thickness (h)	0.813

To find the dimensions of the designed antenna, use the following methods:

$$\lambda o = \frac{c}{f_r} \tag{1}$$

where λo is the wavelength in free space, f_r is the resonant frequency.

To determine the guided wavelength λ_d, we use the formula:

$$\lambda_d = \frac{c}{f_{r\,x}\sqrt{\varepsilon r}} = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \tag{2}$$

In order to determine the transmission line width for 50 ohms (ST_L), we apply the formula:

$$W_f = \frac{2\times h}{\pi} \times \left[B - 1 - \ln(2B-1) + \frac{\varepsilon r - 1}{2\times\varepsilon r} \times \left[\ln(B-1) + 0{,}39 - \frac{0.61}{\varepsilon r}\right]\right] \tag{3}$$

where:

$$B = \frac{60\times\pi^2}{Z_0\times\sqrt{\varepsilon r}} \tag{4}$$

$$\text{If } \frac{\mathbf{W_f}}{\boldsymbol{h}} > 1 \text{ or } \frac{\mathbf{W_f}}{\boldsymbol{h}} < 1 \tag{5}$$

$$\frac{\mathbf{W_f}}{\boldsymbol{h}} > 1\text{, then: } \varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2} \times \left[\frac{1}{\sqrt{1+12\times\frac{h}{W_f}}}\right] \tag{6}$$

$$\frac{W_f}{h} < 1\text{, then} = \varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2} \times \left[\frac{1}{\sqrt{1+12\times\frac{h}{W_f}}} + 0{,}04\times\left(1-\frac{w}{2}\right)^2\right] \tag{7}$$

where ε_{eff} is the effective dielectric constant of the substrate. For calculation of values, C (Arm width) and B (Patch franklin width) can use formulas 1 and 2 by entering the parallel impedance values shown in figure 1.

The slot width (Gap) according to empirical formula can be determined as

$$\text{Gap} = \lambda_d/16 - \lambda_d/8 \tag{8}$$

Finally, we give the guidelines for Dgs (Defected Ground Structure) calculation, which are:

$$\text{DGS Width} = \frac{\lambda d}{4}\text{, DGS Length} = \frac{\lambda d}{4}\text{, DGS Thickness} = \frac{\lambda d}{16} \tag{9}$$

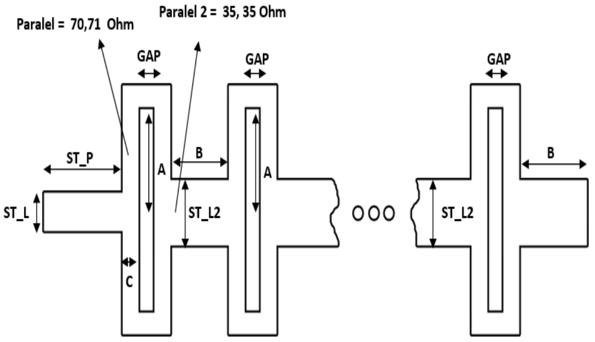


Fig. 1. Dimension of the antenna

Fig. 1 shows the model of the Franklin microstrip antenna. The detailed dimensions are given in Table III.

TABLE III: CALCULATION RESULT

Parameter	Size	Units
Transmission Line Width (W_f) (ST_L)	1,81	mm
Transmission Line Length (L_f) (ST_P)	1,59	mm
Patch Width (W_p) (ST_L2)	3,04	mm
Patch Length (L_p) (B)	2,68	mm
Arm Width (C)	0,98	mm
Total Length Stub (L_{st}) (A)	3,65	mm
Slot Width (Gap)	0,35-0,71	mm
Ground Length (Lg)	36,46	mm
Ground Width (Wg)	15,24	mm
DGS Width	1,42	mm
DGS Length	1,42	mm
DGS Thickness of	0,355	mm

After obtaining the dimensions for each antenna parameter, it is then simulated into Finite Integration in Technique (FIT) or Ansoft HFSS software. Simulation is carried out to obtain the correct antenna dimensions to fit the desired specifications. The simulation here aims to find out how well the antenna performs before it is realized. After the simulation results come out, we can check whether the results have met the specifications or not.

The first one made here is an antenna without using the DGS method. It will be seen how much gain and bandwidth will be generated by antennas without DGS and will be compared with antennas that use DGS.

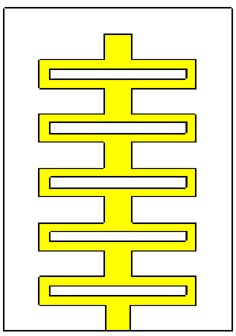


Fig. 2 Front view

The following is the result of the front design (Fig. 2) and rear view (Fig. 3) image following the size of the table of parameter calculation above.

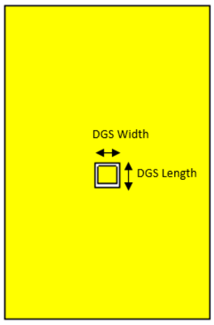


Fig. 3. Rear view

III. ANTENNA RESULTS AND DISCUSSIONS

Simulation and analysis are carried out to obtain data and compare the data obtained from the simulation with the data obtained from the calculation with the existing theory. The analysis was conducted to compare parameters between microstrip antenna without DGS (Defected Ground Structure) with antenna microstrip with DGS (Defected Ground Structure).

At this stage of the simulation, the authors compared the final results of the antenna parameters obtained. Antenna parameters were obtained after optimizing antenna simulation with DGS (Defected Ground Structure) and antenna without using DGS (Defected Ground Structure). In this study, the simulation was conducted using an antenna working frequency designed at 28 GHz; and the simulated substrate is a substrate of Duroid material 4003. After that, we then obtained data on the size of the final antenna parameters used in the manufacture of antennas physically (manufacturing).

TABLE IV: COMPARISON OF FRANKLIN ANTENNA OPTIMIZATION PARAMETERS WITHOUT DGS AND WITH DGS

Parameters	Antenna Optimization without DGS	Antenna Optimization with DGS
Reclection Factor	-28.424 dB	-52.953 dB
Bandwidth	1.512 Ghz	2.86 GHz
Gain	8.521 dBi	11.11 dBi

Table IV compares simulation results to optimize Reflection factor, Bandwidth and Gain Between Franklin Microstrip Antenna Without DGS (Defected Ground Structure) and franklin microstrip antenna With DGS (Defected Ground Structure).

Fig. 4 and Fig. 5 show the comparison of reflection factor and radiation pattern results between Franklin microstrip antenna without DGS (Defected Ground Structure) and Franklin microstrip antenna with DGS (Defected Ground Structure). Fig. 4 there is a difference in the S-parameter value (S11) from the microstrip antenna optimization value with DGS and without DGS. Fig. 4 explains that adding DGS produces a better value of S-Parameter than without using DGS method and optimization value of antenna simulation results with DGS and Without DGS together working at a frequency of 28 GHz. We know the surface waves in microstrip antennas are generated when the substrate has a value of εr > 1. Surface waves reduce the front radiation pattern and increase the back and side lobes. In the case of an antenna array will raise the mutual coupling between array elements in case of increasing the substrate thickness to increase the bandwidth of the surface waves will increase. One of the methods to decrease the surface wave is using DGS (defected ground structure).

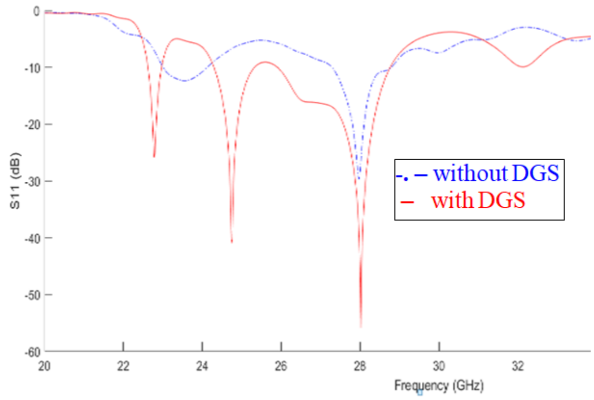


Fig. 4. Reflection factor S-Parameter, without DGS (dashed blue), with DGS (solid red).

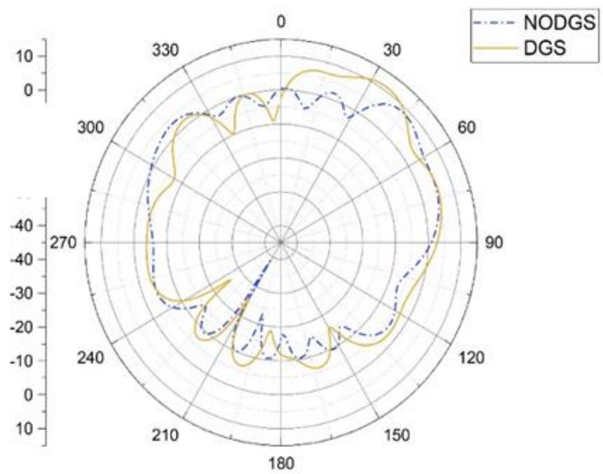


Fig. 5. Radiation pattern

DGS is a form of a sketched pattern on the ground field, or in other words, obtained additional modifications of the ground, in this study in the addition of rectangular-shaped slots with long settings by the matching ability obtained in the optimization process in the simulation. DGS structure in this study will reject a certain frequency or bandgap as is the case in the structure of EBG (electronic bandgap). The design of the franklin antenna is integrated with the addition of DGS. So in this study, the author did change the nature of the waves by adding the DGS pattern (defected ground structure) to the ground plane. The periodic pattern created on this ground plane resembles the periodic patterns in the EBG. The shape of the DGS is modified from an easy slot into a more complex shape. Fig. 5 is an image of antenna simulation results that describe the antenna radiation pattern using DGS and without DGS, that antennas that use DGS produce a more drained radiation pattern in each angle of radiance. Fig. 5 produces the same pattern in which the antenna can emit in all directions.

In the simulation results that have been done, then realized into Franklin Antenna on the mm-wave frequency with the DGS method. The antenna was made using roger droid 4003 base material, after which it was connected with a Female SMA connector on the filling part. The antenna with the optimized dimensions is fabricated, and the measurement of the developed prototype is carried out. The photographs of the prototype are shown in Fig. 6.

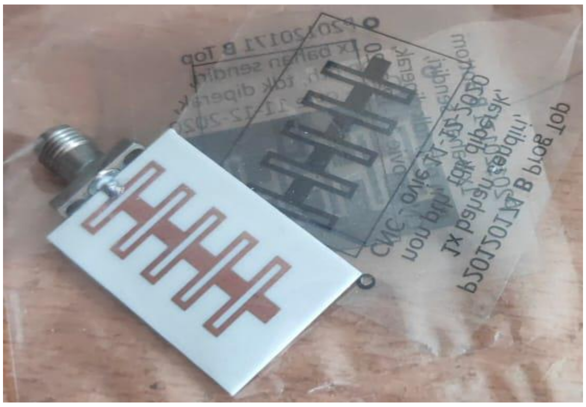


Fig. 6. Fabricated antenna

In this study, research was measured parameters in antennas namely reflection factor. Based on measurements obtained the same frequency results from the simulation. With the reference value of reflection factor of -10 dB.

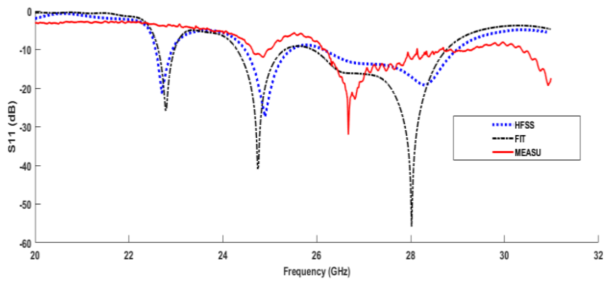


Fig. 7. Reflection factor HFSS vs FIT vs Measurement

Antenna that have been realized will be carried out in the measurement process. Measurements are taken to compare the value of simulation antenna parameters with their prototypes show in Fig. 7, those parameters are, reflection factor from table V, it is seen that the 26.6 GHz band produces a Reflection factor value of -27.72 dB, and bandwith 2 GHz, in this case, the best frequency response value is at a frequency of 26.6 GHz, this happens a shift in frequency response resulting from the simulation with measurement results. This shift occurs due to the influence of the fabrication process, especially the connector soldering process.

The use of high frequencies has an impact on the sensitivity of the measurement process results, the higher the frequency used, the shorter the wave length generated so that if there is material in the antenna aperture, it will result in an increase in aperture, and result in a shift in frequency from the working frequency response. However, the frequency shift results are still on the same level, and still in the working specifications below (Table V):

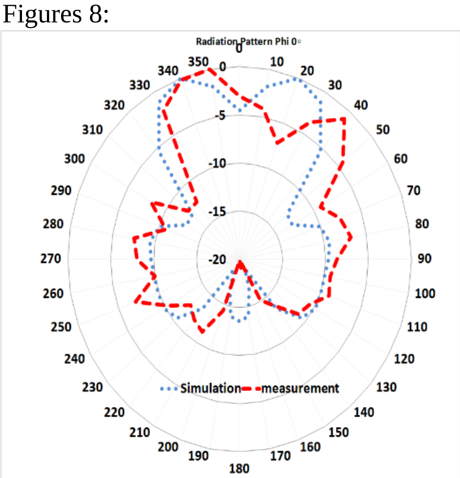
TABEL V. COMPARISON OF SIMULATION AND REALIZATION

Simulations	HFSS	FIT	Measurement
Frequency Center	28	28	26.6
Reflection Factor	-19.23 dB	-52.95 dB	-27.72 dB
Bandwith	2.86 GHz	2.9 GHz	2 GHz

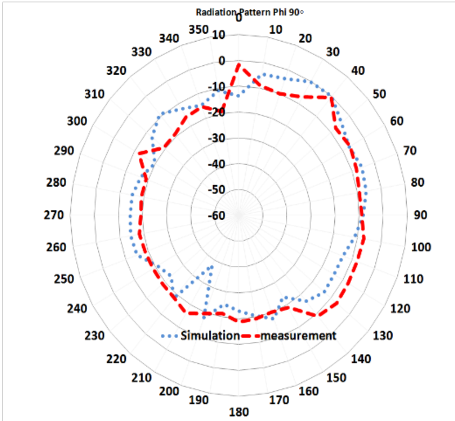
The components Pradiation Measurement contained in the radiation pattern description are the main lobe, sidelobe, and back lobe. The power gain of an antenna is defined as 4π times the ratio of radiation intensity in that direction to the antenna's receiving power from a connected transmitter, usually the direction in question is the maximum radiation direction. While the relative gain is the comparison of power gain in a certain direction to the gain of antenna power in the direction of reference. A good reference antenna for use is an isotropic antenna where the antenna has the same reinforcement at each point, but in reality, the isotropic antenna does not exist.

So in this measurement as a reference antenna is used Horn antenna that has the same frequency of work as the antenna to be measured. Antenna radiation patterns are measured in distant terrain areas of antennas because in that area the radiated electromagnetic waves are full transverse and antennas are not affected by surrounding objects. Antenna radiation patterns are measured on the surface of the ball with a constant radius.

Data obtained from radiation pattern measurement results is a comparison of received power and power sent (Pr / Pt) in dB. Then the data is processed and normalized. From the processing of data can be obtained radiation patterns on two perpendicular fields (fields E and H) as seen in Figures 8:



(a)



(b)

Fig. 8. Simulation polarization results – (a) Measurement based on azimuth (E-field), (b) measurement by Elevation (H-field)

From Figures 8 can be seen as a graphic image of radiation patterns. The graph was obtained by measuring radiation patterns in far-field areas. Can be seen from the radiation pattern obtained in the first beamwidth that is 28 GHz tends to be unidirectional good for its E field. For field E the maximum main lobe leads to an angle of 340 degrees and 40 degrees for antennas with DGS. As for the field, H leads to 360 degrees with the fluctuations of the amplitude level of each degree from the results of measurement and simulation there are several different angles, this is because the same as the explanation that has been explained before the existence of factor2 that makes a difference, due to the use of high frequencies. Besides, the room in use still produces some reflections that can be from the reflection of electromagnetic waves on the measuring instrument used, because the measuring instrument is in the same room in the anchic chamber.

The ratio of gain generated between Finite Integration in Technique (FIT) and Ansoft HFSS software simulation. In the Finite Integration in Technique (FIT) produced a gain of 11.11 dB, and in the simulation Ansoft HFSS resulted in a gain of 11.81 dB. the graph in figure 10 compiled from the export data gain Phi 90 degrees from each software using ASCII / text / CSV format and then compared the data.

The characteristics of the antenna to be analyzed next are radiation patterns and gain. The radiation pattern of an antenna is an illustration of the intensity of the antenna beam as a function of the coordinate parameters of the sphere (θ,φ).

The components contained in the radiation pattern description are the main lobe, sidelobe, and back lobe. The power gain of an antenna is defined as 4π times the ratio of radiation intensity in that direction to the antenna's acceptability from the connected transmitter, usually the direction in question is the maximum radiation direction. While the relative gain is the comparison of power gain in a certain direction to the power gain of the antenna in the direction of reference. A good reference antenna to use is an isotropic antenna where it has the same reinforcement at every point, but in reality, the isotropic antenna does not exist. So in this measurement as a reference antenna used a Horn antenna that has the same working frequency as the antenna to be measured. Antenna radiation patterns are measured in the antenna's remote terrain area because in that area the electromagnetic waves emitted are fully transverse and the antenna is not affected by the surrounding objects. Antenna radiation patterns are measured on the surface of the sphere with a constant radius.

In this study the method used in gain measurement is using two identical antennas namely on the sender and receiver side, what distinguishes is the measurement of gain Antenna Under Test does not need to be rotated in the direction of the azimuth. Gain Measurement of ordinary condition gain is done with 10 times the sample, from the average result of the measurement, the calculation of the gain is 9.7223 dB. The result is close to the desired antenna specification of ≥ 10 dBi. As shown in the following Table VI:

TABLE VI. GAIN MEASUREMENT SAMPLE

Measurement Gain		
Measurement Sample	Receiving Power (dBm)	Receiving Power (mW)
1	-57,75	1,6788E-06
2	-57,6	1,7378E-06
3	-57,45	1,79887E-06
4	-57,81	1,65577E-06
5	-57,9	1,62181E-06
6	-57,1	1,94984E-06
7	-57,87	1,63305E-06
8	-57,78	1,66725E-06
9	-57,2	1,90546E-06
10	-57,78	1,66725E-06
Average	-57,61554742	1,73159E-06

Table VII shows a comparison of simulation results gain in Ansoft HFSS software with measurement results.

TABLE VII. COMPARISON OF GAIN SIMULATION & MEASUREMENT

Parameters	Finite Integration in Technique (FIT)	Simulation Ansoft HFSS	Measurement
Gain	11.11 dBi	11.81 dBi	9.7223 dBi

Can be compared the overall parameters of the antenna, during simulation and realization of differences in value. The difference in results between simulation and realization can be caused at the time of antenna fabrication that is less precise.

IV. CONCLUSION

In the design of the study antenna is by the desired specifications can work at a working frequency 5G. This research produces a bandwidth of 1.707 GHz from 1.196 GHz without DGS (Defected Ground Structure) to 2.9 GHz with DGS (Defected Ground Structure) or 142.47%. The increase in gain was also generated by 141.7 %. Franklin microstrip antenna output with DGS (Defected Ground Structure) method from the research simulation results are the bandwidth of 2.9 GHz, reflection factor of -52.95 dB and Gain of 11.80 dB. Hybrid antenna measurement results produce bandwidth of 2 GHz, reflection factor -27.72 dB, and Gain 9.7223 dBi. Measurement of ordinary condition gain is done with 10 times the sample, from the average result of the measurement, the calculation of the gain is 9.7223 dB. Addition of DGS (Defected Ground Structure) on franklin microstrip antenna can increase Bandwidth and Gain.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest concerning the publication of this paper.

AUTHOR CONTRIBUTIONS

In this paper, all the authors have their contributions. AF wrote an idea, determined the working frequency of the franklin antenna, and calculated the mathematical algorithm before carrying out the simulation, IW carried out simulations and design optimization to get the appropriate results and fabricated the antenna, MA assembled and measured the fabricated antenna. All authors had approved the final version.

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