Effect of Parasitic Patch for the Radiation Characteristics Microstrip Antenna Planar Array with Distribution Edge

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Abstract—**Power Domain Non-Orthogonal Multiple Access (PD-NOMA) is one of the multiple access schemes that increase a channel capacity by focusing on the downlink side. This study stems from the facilitation of various narrow and sharp beams with a high gain and directivity, so the users can maximize each of the sharp beams and have higher power efficiency. The higher the power efficiency is, the higher the throughput will be since it is directly proportional to the increased channel capacity. This study employs an edge weight to design the arrangement of a planar microstrip antenna with the uniformly-spaced N elements (λ/2). The antenna design starts from 1x3 to 1x6, and it will produce a multi-beam pattern with a 5G 2.6-GHz operating frequency. Each patch is separated by λ /2 employing a parasitic and a non-parasitic patch, with the value of S_{11} amounting to below -20 dB. There is a novelty in this study in that it is found out that the characteristic of the number of the main lobes for the antenna's even number is N+1, and the characteristic of the number of the main lobes for the antenna's odd number is N. With the multi-beam characteristics that are narrow and sharp, the gain and directivity values are getting higher. Furthermore, the parasitic patches or no parasitic patches only affect the side lobe and do not significantly affect the main lobe.**

Keywords—**microstrip patch, odd and even number of patches, radiation pattern characteristics, S11, An edge distribution**

I. Introduction

Power Domain Non-Orthogonal Multiple Access (PD-NOMA) is a multiple access scheme that increases a channel capacity by focusing on the downlink side. The state of this study comes from the idea of facilitating a multiple, narrow, and sharp beam with a high gain and directivity, so each of the users can maximize each of those sharp beams and have higher power efficiency. The throughput is expected to increase by increasing the power efficiency directly proportional to the increased capacity of the channels.

Therefore, this study is aimed at facilitating the expansion of the channel capacity expansion by designing an antenna producing a radiation pattern with a multi-beam and sharpness with a gain that meets the non-mobile 5G communication standards despite the fact that many studies have focused on various antennas in some mobile applications such as Ref. [1–3]. This designed antenna employs a microstrip antenna with a planar configuration using an edge distribution.

Based on the results of the brief analysis pursuant to some of those studies above, it is decided that this study employs an edge-type current distribution, a subset of Dolph-Chebyshev. By adding the distance between the two elements of the antenna, the number of sharp and narrow main lobes can be increased.

Therefore, when designing the proposed arrangement of this planar microstrip antenna starting from 1×3 to 1×6 dimensions at the 5G 2.6-GHz operating frequency, the characteristics of the radiation pattern on the number of main lobes with the optimal gain and directivity parameter values will be investigated.

In this study, each patch is separated with λ/2 by employing a parasitic patch and using no parasitic patches, with the value of S_{11} amounting to below −20 dB. This antenna is designed by using a standard size value of the return loss (RL) below −20 dB. RL is a quantity expressing the ratio of the reflected power to the received power. The mathematical formula of RL is as follows. The excellent value of VSWR (close to 1) will be obtained.

VSWR (Voltage Standing Wave Ratio) is the ratio of the magnitude of the maximum voltage to the magnitude of the minimum voltage on a standing wave at a point on a transmission line. By maximizing the effort to get a small RL value and the maximum VSWR, it is found out that the supply process is maximized in the antenna designed in the middle position. The characteristics of the radiation pattern from the full antenna beam will form a new main lobe which affects the total gain of the antenna.

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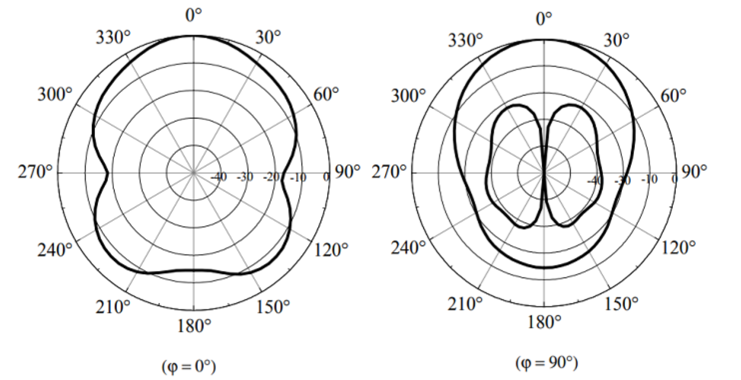
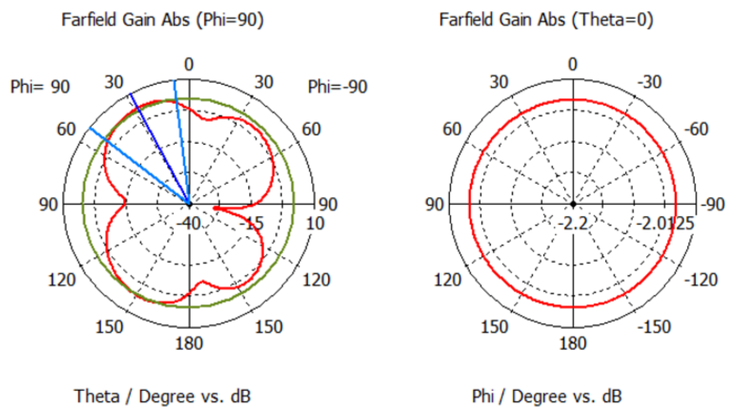
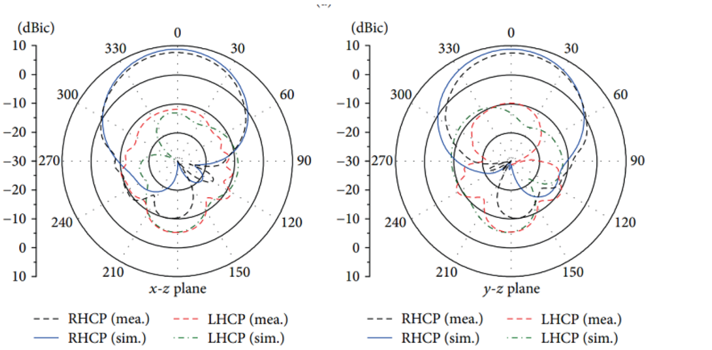
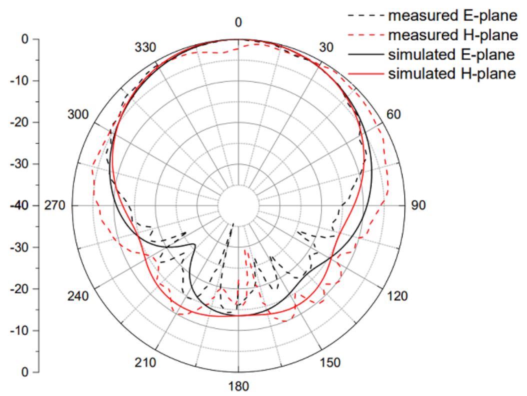
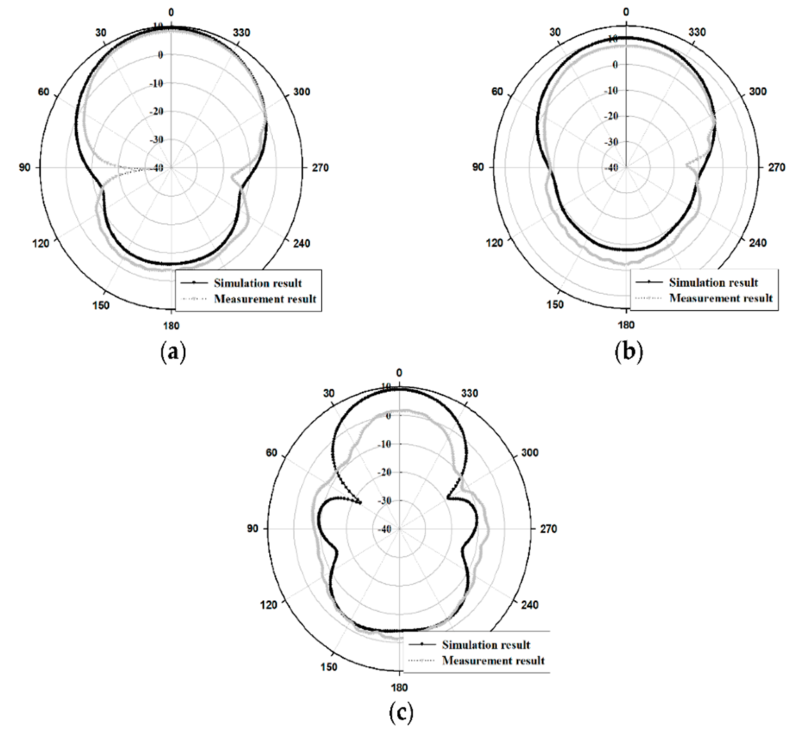
Table I shows some studies on various microstrip antennas serving as the references in the production of a multi-beam radiation pattern. They are as follows:

After the simulated antenna is designed and the optimal results are obtained, the characteristics of the radiation pattern in terms of its gain and directivity are tested.

TABLE I. COMPARISON OF MICROSTRIP ANTENNA STUDIES WITH PARASITIC PATCHES

Ref.	Antenna	Method	Performance Improvement	
			Gain	Polar Radiation
Pan *et al.* [4]	Single antenna (3 layers)	patch modification	8.9 dBi within the passband	
Elo *et al.* [5]	Single rectangular antena	addition of a parasitic patch on top of the patch	4.47 dB	
Ta *et al* [6]	Single rectangular antena	addition of a parasitic patch under the patch	7.8–8.7 dBic	
Da *et al* [7]	Single triangular patch	addition of a parasitic patch around the triangular patch	-	

Kim *et al* [8]	Single rectangular antena	Beam steering	8dBi	

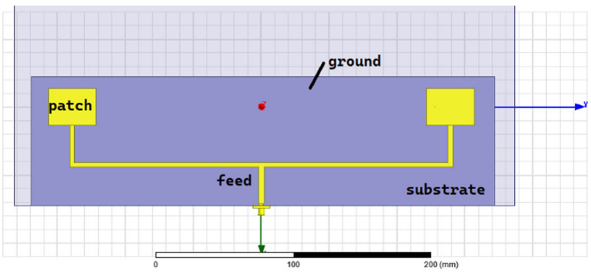


Figure 1. Conventional patch microstrip antenna.

There is a novelty in the design of this N planar element microstrip antenna with uniform spacing (λ/2) and with several side weights in that the number of main lobes for the antenna is odd, and even; then, a parasitic patch will be added or no parasitic patches will be added to find out whether or not it will significantly impact on the performance of the antenna.

II. Antenna Design

A. Antenna Patch Microstrip

One type of antennas widely used in various applications of the wireless communication system is a patch microstrip antenna. This antenna has several advantages on account of its size, its physique, its simple profile, and the ease of its fabrication. However, this antenna has some limitations in regards to its bandwidth, gain and efficiency[9]. Fig. 1 shows the manufacture of a Microstrip antenna Conventional patch using a printed circuit board technology (PCB).

Fig. 1 shows a conventional patch microstrip antenna consisting of a radiating patch and a substrate with dielectric, charge, and ground constants. The following is the variable measurement formula of the designed antenna [10]:

- Patch width

$$\text{Width(W)} = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}}; \tag{1}$$

- Patch length

Effective Dielectric Constant calculations are based on the dielectric's height, dielectric constant, and the patch antenna's calculated width.

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right] \tag{2}$$

Effective length calculation:

$$L_{\text{eff}} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} \tag{3}$$

Length extension calculation of ΔL:

$$\Delta L = 0.412\,h\,\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

Actual patch length calculation:

$$L = L_{\text{eff}} - 2\Delta L \tag{5}$$

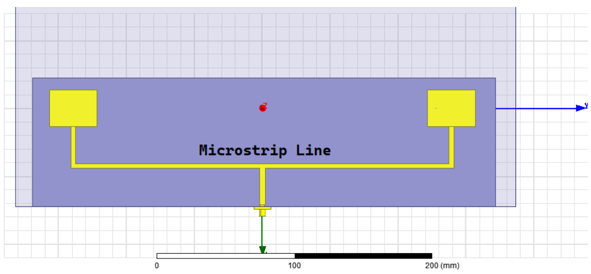


Figure 2. Schematic of microstrip line distribution.

where:
W is the width of the patch (mm)
f_0 is the resonance frequency (GHz)
ε_R is the dielectric constant (F/m)
ε_{eff} is the effective dielectric constant
L_{eff} is the effective length (mm)
ΔL is the length extension (mm)
h is the thickness of substrate (mm)
L is the length of the patch (mm)

B. *Microstrip FeedLine*

In this supply line type, the line is directly connected to the edge of the microstrip patch as shown in Fig. 2. The insertion of a cut-in in this patch is aimed at matching the impedance of the line to the patch without having to add any other matching elements.

The scheme for the making of this channel is quite simple; however, it must be with a thin thickness of the substrate dielectric since the channel radiation also produces unwanted polarized radiation. Therefore, it needs to be arranged in such a way in order to achieve the desired resonant frequency and to produce a slight return loss.

C. *Antenna Array*

Total field E_t of 2 3d spaced elements [11]:

$$E_t = 2E_0 \cos 3\frac{\varphi}{2} \tag{6}$$

Hence, the combined field E_t of the 2 elements is space **d** as shown at Fig. 3:

$$E_t = E_0 e^{j\frac{\varphi}{2}} + E_0 e^{-j\frac{\varphi}{2}} = 2E_0 \cos\frac{\varphi}{2} \tag{7}$$

With Value $\varphi = d_r \cos\phi$ and $d_r = \frac{2\pi}{\lambda} d$. Then, shown at Fig. 4:

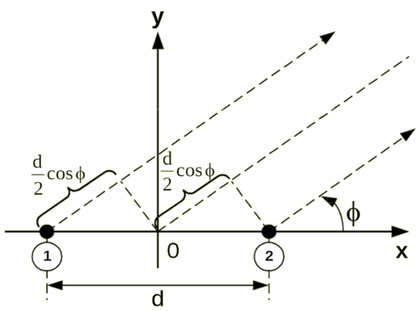


Figure 3. Antenna array with uniform spacing.

D. *EDGE Distribution*

The EDGE distribution is part of the Dolph-Chebychev weighting. In Dolph-Chebychev, the number of odd and even elements has the following formula [12]:

$$\begin{aligned} Odd = E_{ne} &= 2\sum_{k=0}^{k=N-1} A_k \cos\left([2k+1]\frac{\varphi}{2}\right) \\ \text{Even} = E_{no} &= 2\sum_{k=0}^{k=N} A_k \cos\left([2k]\frac{\varphi}{2}\right) \end{aligned} \tag{8}$$

where:
E_{ne} is even number of elements.
E_{no} is odd number of elements.
k is N for odd number or N-1 for even number.
N is elemen antenna.
φ is $d_r \cos\phi$.
ϕ is angle 0-360°.

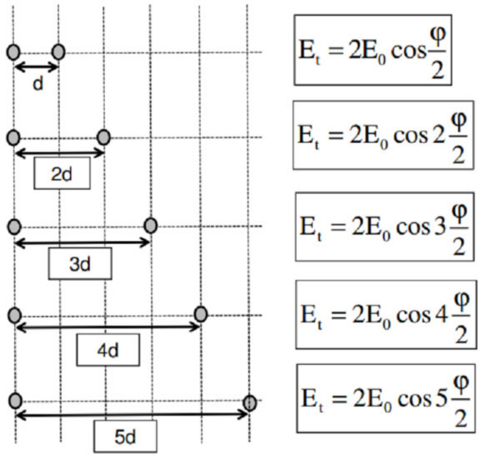


Figure 4. The field generated by an array antenna with uniform spacing.

Radiation Characteristics:

The two equations above can be seen as a Fourier series with finite terms. A pair of terms represents a "pair" of sources. Furthermore, A pair is the sum of the dc constants, the fundamental, and the harmonics. At each distance λ, 2λ, 3λ, 4λ and so on will produce a new main lobe by supplying only the patches at the right and left ends, as shown in Figure 5 above.

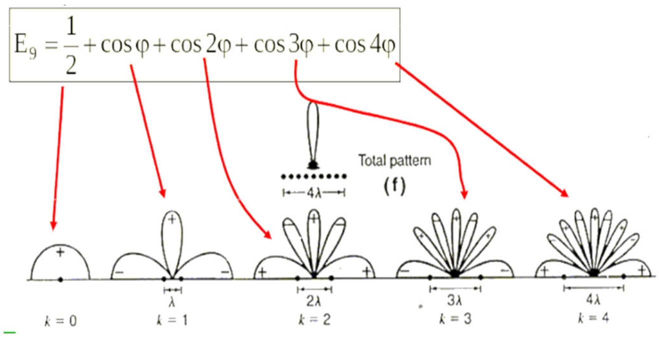


Figure 5. Antenna array with uniform spacing.

E. *Return Loss*

The mathematical formula of the *Return* Loss (RL) is as follows:

$$RL(z) = \frac{P_{ref}}{P_{inc}} = \frac{\frac{(V^-(z))^2}{R}}{\frac{(V^+(z))^2}{R}} = |\Gamma_v(z)|^2 = 10\log\left(\frac{P_{ref}}{P_{inc}}\right) = 10\log|\Gamma_v(z)|^2 = 20\log|\Gamma_v(z) \tag{9}$$

VSWR (Voltage Standing Wave Ratio) is the ratio of the magnitude of the maximum voltage to the magnitude of the minimum voltage on a standing wave at a point on a transmission line [13].

$$\mathrm{VSWR}(z) = \frac{|V(z)|_{\max}}{|V(z)|_{\min}} = \frac{|V^+(z)+V^+(z)\Gamma_v(z)|}{|V^+(z)-V^+(z)\Gamma_v(z)|} = \frac{(1+|\Gamma_v(z)|)|V^+(z)|}{(1-|\Gamma_v(z)|)|V^+(z)|} = \frac{1+|\Gamma_v(z)|}{1-|\Gamma_v(z)|} \quad (10)$$

where:

RL(z) is return loss
P_{ref} is reflected power
P_{inc} is incoming power
V^- (z) is reflected wave voltage
V^+ (z) is incident wave voltage
$V(z)_{max}$ is maximum voltage magnitude
V(z)min is minimum voltage magnitude
Γ_v (z) is voltage reflection coefficient

The maximization of the RL value and VSWR shows that the characteristic of the radiation pattern deriving from the full of planar antenna beam will form a new main lobe affecting the total gain of the antenna.

F. Radiation Pattern

The radiation pattern is a graphical representation of the transmitting properties of an antenna as a function of space coordinates. By using the radiation slot model above, the electric field equation [11] applies: for

$$E = E_x\bar{x} \ \text{ for } \ |\bar{x}| \le \frac{h}{2} \quad (11)$$

A unidirectional antenna has a directional radiation pattern and can cover a relatively long distance.

G. Gain

Gain is the ratio of the unit power density of the antenna unit to the reference antenna power density in the same direction and input power. An antenna's gain differs from the four-pole's gain, and the gain is taken into account by the input power to the antenna terminal. Gain is obtained by using the equation [11]:

$$G = \eta \times D \quad (12)$$

The input power between the two antennas must be the same. However, the reference antenna is a lossless isotropic source (Pin(lossless)).

H. Beamwidth

Beamwidth is the angle of the main lobe radio frequency beam calculated at a 3-dB point down from the top of the main lobe. The amount of beamwidth is as follows [14]:

$$B = \frac{21{,}1}{f \times d} \quad (13)$$

where:

B is 3dB beamwidth (degree)
d is antenna diameter (degree)

If beamwidth refers to the gain of a radiation pattern, it can be formulated as follows:

$$\beta = \theta_2 - \theta_1 \quad (14)$$

I. Characteristic Impedance of Microstrip Line

In principle, a microstrip antenna is similar to a microstrip channel in that it determines the width of the channel or the radiation element. Mathematically, the value of the characteristic impedance for a microstrip antenna line can be calculated by using the following equation:

$$Z_0 = \frac{3}{\sqrt{\varepsilon_r W}} \ (\Omega) \quad (15)$$

where:

Z_0 is characteristic impedance (Ω)
W is the width of the patch (mm)
ε_R is the dielectric constant (F/m)
h is the thickness of substrate

III. Result and Discussion

A. Result

The microstrip array antennas are in the 1×3, 1×4, 1×5, and 1×6 configurations. In this design, the design of the antenna is modified by using a parasitic or by using no parasitic patches with a non-uniform edge distribution supply. The standard antenna parameters are return loss below -20 dB which works at a 2.6-GHz frequency — the antenna radiation pattern with an odd element configuration is represented by the 1×3 and 1×5 designs. Furthermore, the antennas with an even element configuration are represented by the 1×4 and 1×6 designs.

Each of the antenna configurations is separated with the same distance, namely λ/2, weighing only on the right and left ends. Table I describes the performance of the antenna in a simulation by comparing the amount of return loss, VSWR, and the accuracy of the operating frequency in the design using a parasitic patch and no parasitic patches. Next, the configuration design producing the biggest beam, the highest gain, and the obtained bandwidth is discussed.

B. 1×3 Antenna Design with a Parasitic Patch and without a Parasitic Patch

The 1×3 odd antenna scheme is designed as follows. The distance between the patches is λ/2, and the planar three patch antennas using a parasitic patch and without using a parasitic patch weigh 1-0-1 as shown in Fig. 6 and Fig. 7 below.

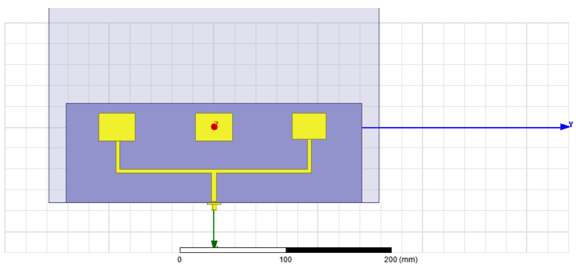


Figure 6. 1×3 antenna design without parasitic.

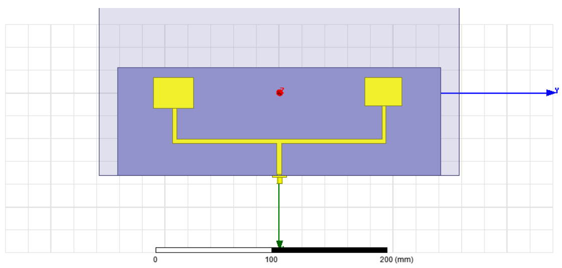


Figure 7. 1×3 antenna design with parasitic.

Based on the results of the simulation for the 1×3 design, it is found out that, in the antenna design with a parasitic patch, the return loss is –27.3616 dB and VSWR is 0.7448. Meanwhile, in the antenna design without any parasitic patches, the return loss is –27.7769 dB and VSWR is 0.7100.

TABLE II. 1×3 ANTENNA DESIGN

Configuration		Freq.(GHz)	S_{11} (db)	VSWR
1×3	With parasitic	2.58	-27.3616	0.7448
	Without-parasitic	2.58	-27.7769	0.7100

Thus, Table II shown the 1×3 design without a parasitic patch performs better than the design with a parasitic patch although their performances are not significantly different.

C. 1×4 Antenna Design with a Parasitic Patch and without a Parasitic Patch

The 1×4 odd antenna scheme is designed as follows. The distance between the patches is λ/2, and the planar five patch antennas using a parasitic patch and without using a parasitic patch weigh 1-0-0-1 as shown in Fig. 8 and Fig. 9 below.

Based on the results of the simulation for the 1×4 design, it is found out that, in the antenna design with a parasitic patch, the return loss is –23.6233 dB, and VSWR is 1.1463. Meanwhile, in the antenna design without any parasitic patches, the result loss is –22.8114 dB, and VSWR is 1.2590.

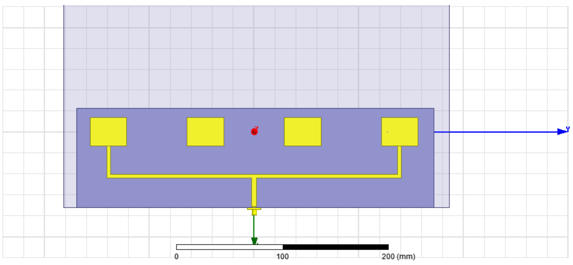


Figure 8. 1×4 antenna design with with parasitic

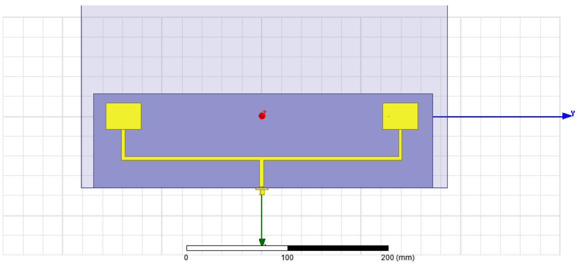


Figure 9. 1×4 antenna design with without parasitic.

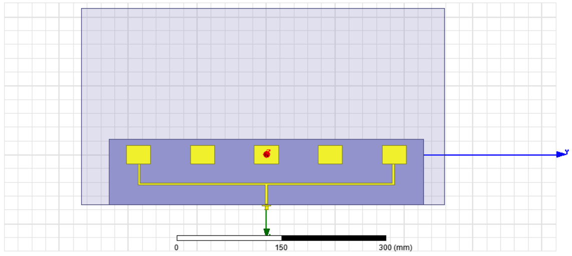


Figure 10. 1×5 antenna design with parasitic.

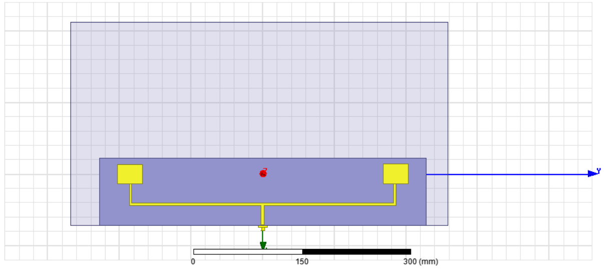


Figure 11. 1×5 antenna design without parasitic.

TABLE III. 1×4 ANTENNA DESIGN

Configuration		Freq.(GHz)	Return Loss (db)	VSWR
1×4	With parasitic	2.48	-23,6233	1,1463
	Without-parasitic	2.48	-22,8114	1,2590

Thus, Table III shown the 1×4 design with a parasitic patch performs better than the design without a parasitic patch although their performances are not significantly different.

D. 1×5 Antenna Design with a Parasitic Patch and without a Parasitic Patch

The 1×5 even antenna scheme is designed as follows. The distance between the patches is λ/2, and the planar five patch antennas using a parasitic patch and without using a parasitic patch weigh 1-0-0-0-1 as shown in Fig. 10 and Fig. 11 below.

TABLE IV. 1×5 ANTENNA DESIGN

Configuration		Freq.(GHz)	Return Loss (db)	VWSR
1×5	With parasitic	2.6	-25.8168	1.1079
	Without-parasitic	2.6	-27.5033	0.7327

Based on the results of the simulation for the 1×5 design, it is found out that, in the antenna design with a parasitic patch, the return loss is –25.8168 dB and VSWR is 1,1079. Meanwhile, in the antenna design without any parasitic patches, the return loss is –27.5033 dB and VSWR is 0/7327.

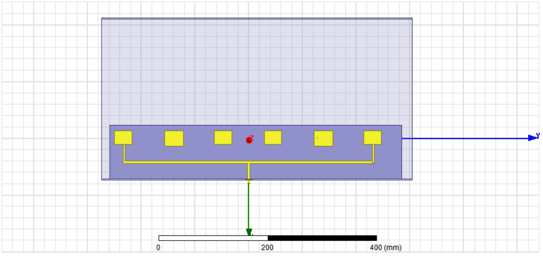


Figure 12. 1×6 antenna design with parasitic.

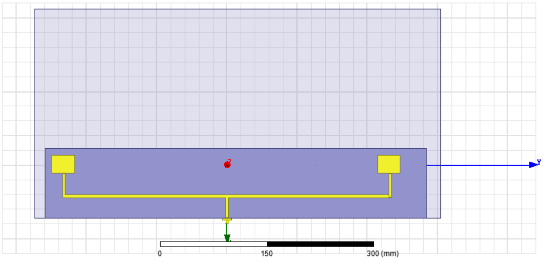


Figure 13. 1×6 antenna design with without parasitic.

Thus, Table IV shown the 1×5 design without a parasitic patch performs better than the design with a parasitic patch although their performances are not significantly different.

E. 1×6 Antenna Design with a Parasitic Patch and without a Parasitic Patch

The 1×6 odd antenna scheme is designed as follows. The distance between the patches is λ/2, and the planar six patch antennas using a parasitic patch and without using a parasitic patch weigh 1-0-0-0-0-1 as shown in Fig. 12 and Fig. 13 below.

TABLE V. 1×6 ANTENNA DESIGN

Configuration		Freq. (GHz)	Return Loss (db)	VSWR
1×6	With parasitic	2.56	-21.0980	1.5349
	Without-parasitic	2.56	-18.8973	2.2477

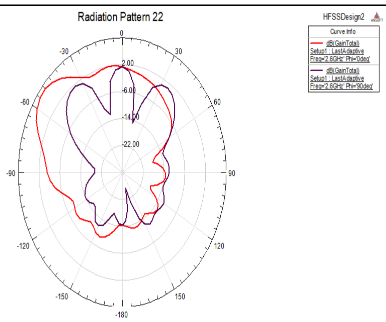
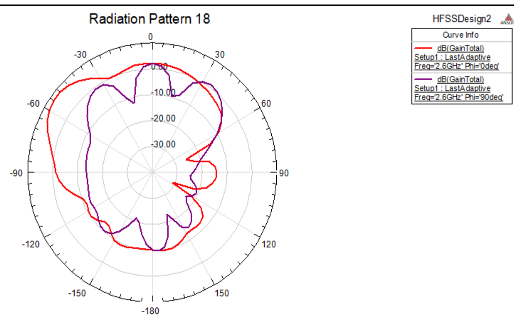
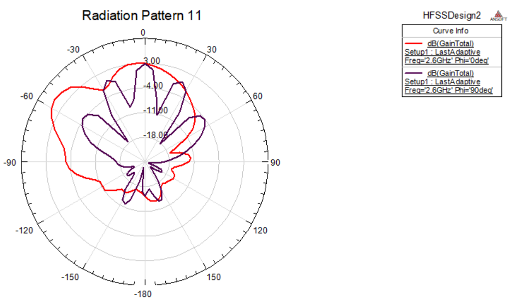
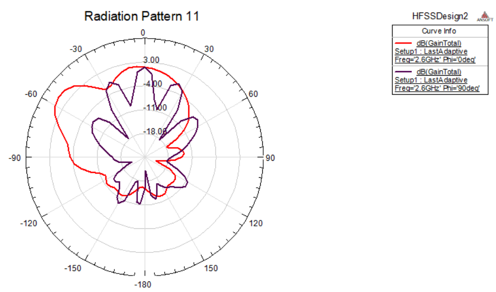
Based on the results of the simulation for the 1×6 design, it is found out that, in the antenna design with a parasitic patch, the return loss is –21.0980 dB, and VSWR is 1.5349. Meanwhile, in the antenna design without any parasitic patches, the return loss is –18.8973 dB, and VSWR is 2.2477.

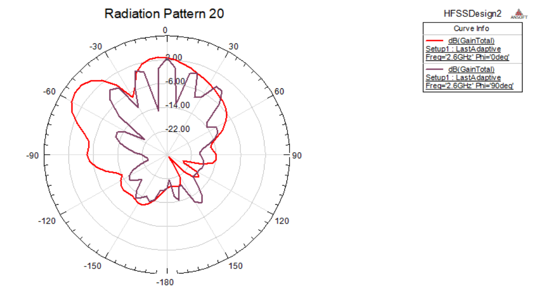
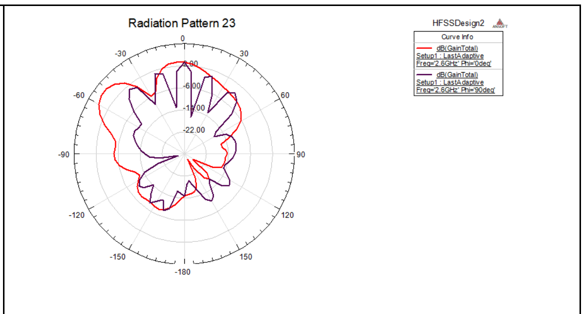
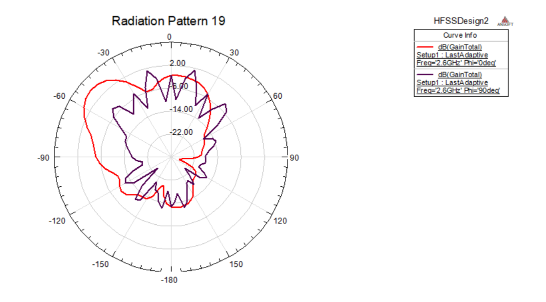
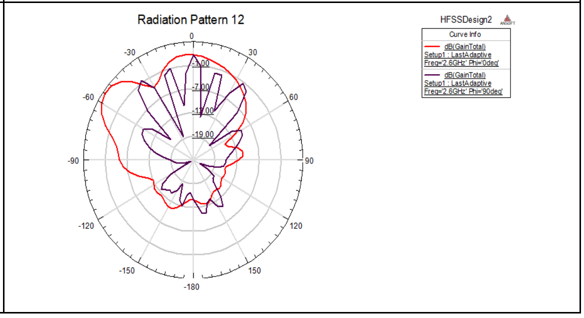
Thus, Table V shown the 1×6 design with a parasitic patch performs better than the design without a parasitic patch although the performances are not significantly different.

F. Gain Total with Parasitic and without-Parasitic

Table VI is the antenna radiation pattern based on the received total gain using a parasitic patch and without using a parasitic patch. The image shows the radiation pattern at phi amounting to from 0 degrees to 90 degrees to theta angle amounting to from 0 degree to 360 degrees. At the 90-degree radiation pattern, the additional main lobe is more visible than that of 0 degrees phi.

TABLE VI. ANTENNA RADIATION PATTERN WITH PARASITIC AND WITHOUT PARASITIC

Description	With Patch Parasitic	Without Patch Parasitic
1×3		
1×4		

1×5		
1×6		

Furthermore, each branch of an antenna element adds a new main lobe. For antenna element 3, there are three main lobes. For antenna element 4, there are five main lobes. For antenna element 5, there are five main lobes. For antenna element 6, there are seven main lobes.

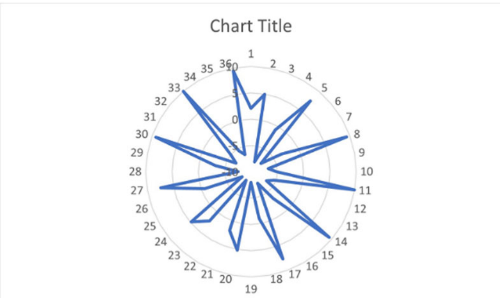


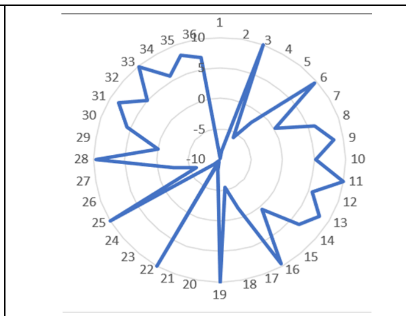
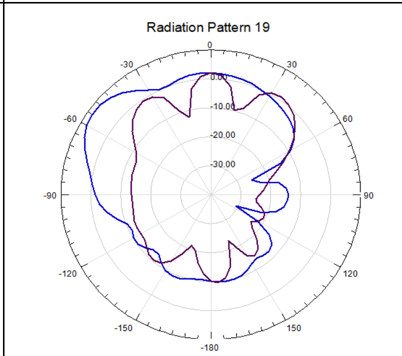
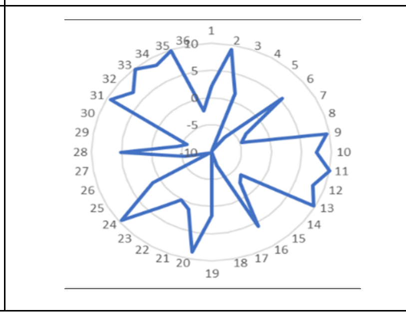
Figure 14. The addition of a new main lobe evenly distributed at 360 degrees in the distribution of edges.

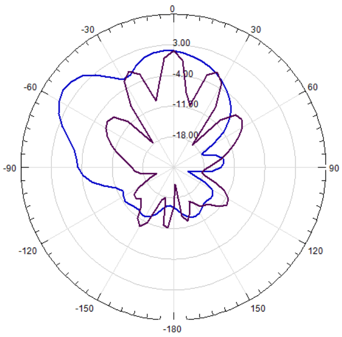
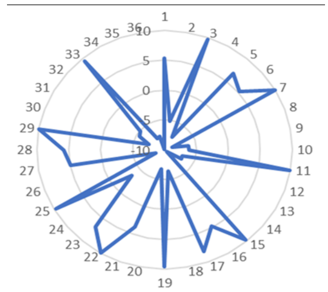
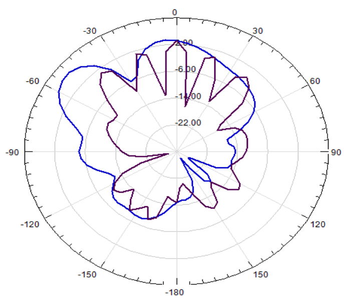
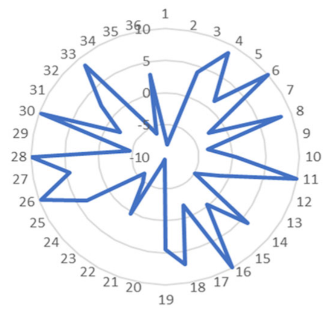
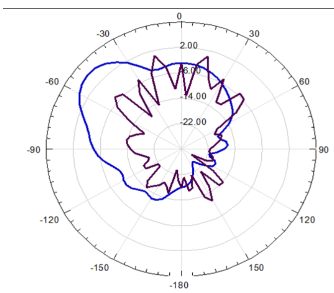
An additional parasitic patch or no parasitic patch does not significantly impact on the number of main lobes, it significantly impact on the number of side lobes/ Moreover, it does not significantly change the gain value, either.

G. *Main Lobe Using N even and Odd*

According to the distribution edge theory, every distance between the antennas, such as λ, 2λ, 3λ, 4λ, will produce a new main lobe by supplying the power at the right and left ends only. However, this distribution edge theory with point antennas will be compared to the microstrip patch as shown in Fig. 14.

TABLE VII. 1×5 COMPARE RADIATION PATTERNS BASED ON MATHEMATICAL FORMULAS AT POINT CONDITIONS WITH A 1XN PLANAR MICROSTRIP ANTENNA SIMULATION

N-Antenna	1×3	Number of main lobes
Math. result		3
Simulation result		3
N-Antenna	1×4	Number of main lobes
Math. result		5

Simulation result		5
N-Antenna	1×5	Number of main lobes
Math. result		5
Simulation result		5
N-Antenna	1×6	Number of main lobes
Math. result		7
Simulation result		7

A multi-beam radiation pattern characteristic is obtained by designing an N-element planar microstrip antenna arrangement at uniform spacing (λ/2) with several edge weights. Furthermore, Table VII shows the comparison.

Based on the number of main lobes in the radiation pattern as shown in Fig. 10 and Fig. 11, it is found out that the pattern of the number of main lobes obtained from N odd is N and N even, namely many N+1.

IV. Conclusion

Having compared the theory and the simulation of antennas separated by various lambda distances, several conclusions are drawn. An additional distance will produce a new main lobe. Then, the distance between the two antennas, which are spaced as far apart as N antenna elements, forms a pattern of the number of main lobes of N on N odd antenna elements and N+1 on the number of antennas of N. Adding a parasitic patch or not adding a parasitic patch in the middle does not significantly impact on the number of the main lobes, but it significantly impacts on the side lobe. Hence, the total gain insignificantly changes after a parasitic patch is used.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

Conceptualization, I.U.V.M., A.K; methodology, I.U.V.M., C.; software; validation; formal analysis; inquiry; resources; data curation; writing—original draft preparation; writing—review and editing, I.U.V.M., A.K.; visualization; supervision; project management; and financing acquisition are all skills that I.U.V.M., A.K. possesses; all authors have approved the final version.

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