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Antenna for 5G Mobile Communication at 28 GHz

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Abstract: Fifth generation (5G) mobile communications has become one of the trendiest issues in recent years, especially in the development of wireless technology for communications. As such, 5G mobile communications will also suffer severe path loss, due to the high frequency bands. This work presents the antennas for 5G mobile communication at 28 GHz on Rogers RT5880 with a dielectric constant, ε_r of 2.2, loss tangent, tan δ of 0.0009 and thickness, h of 0.787 mm. A rectangular microstrip patch are proposed in this work which consist of a single element and array configurations with two and four elements. Microstrip feed line and inset feed line are implemented to observe their performances. It can be observed from the simulation results that the gain and directivity increase from a single element up until four elements array antenna for both the microstrip feed line and inset feed line of the rectangular microstrip patch antenna. This confirm to the fact that array antenna produces high gain and directivity which could overcome the challenge of high free space path loss in millimeter-wave. The spacing between each element in the array antenna are spaced accordingly and not so close with each other in order to suppress the mutual coupling between the elements. It is shown that the mutual coupling is greatly reduced based on the greater values of reflection coefficient in two-element and four-element array antennas. Based on the gain, directivity and reflection coefficient, inset feed line antennas perform better than microstrip feed line antennas. In terms of dimensions, the size of the antenna with an inset feed line reduces as compared to microstrip feed line as the number of elements increases. Thus, it is safe to conclude that inset feed line antennas outperform microstrip feed line antennas when it comes to gain, directivity, reflection coefficient, and dimensions of antennas. Therefore, the proposed array antennas in this work are suitable to be used in 5G mobile communications.

Keyword: 5G, Microstrip antenna, Array antenna, High gain, High directivity

1. Introduction

Wireless mobile communications have undergone a strong evolution over the last decades, used by increasing number of applications and services [1]. In recent years, the fifth-generation (5G) wireless connection technology has gained more attention and popularity. This technology is an extension of the previous generation from the first-generation (1G) to fourth-generation (4G) [2]. The 5G is expected to provide solutions to the scarcity rising from 4G such as restricted bandwidth and speed. Malaysian Communications and Multimedia Commissions (MCMC) has taking an innovative approach on the allocation of spectrum bands and setting a critical foundation for the transition towards 5G. Therefore, to cater for the needs, 700 MHz, 3.5 GHz and 26/28 GHz bands have been identified for the initial deployment of 5G in Malaysia. The 26.5 GHz to 28.1 GHz frequency bands will be assigned on a first-come first-served basis and are open to any parties (including non-licensees) for the purpose of deploying localised or private networks [3].

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Millimetre-wave (mm-Wave) antenna is one of the vital components in 5G communication system. To date, microstrip antennas have been prevalent because of their simplicity, low profile, light weight and compatibility with integrated circuits [4]. Therefore, for that reason, microstrip antennas have been one of the best candidate to implement antennas operating at millimetre wave band for 5G wireless mobile communication systems. One of the main challenges in 5G mobile communication is the high free space path loss for millimeter-wave in comparison to the current frequencies that are used in 4G and 3G [5]. Another challenge would be to design millimeter-wave antennas in array configurations that are smaller in size (due to their smaller wavelength) as it might introduce mutual coupling between the elements.

Therefore, to overcome those challenges, microstrip antennas in array configurations are proposed for 5G mobile communication at 28 GHz. The 28 GHz frequency is chosen from the fact that it is one of the frequency bands allocated for 5G by MCMC Malaysia. On the other hand, an array configuration is commonly deployed to increase the gain and directivity of an antenna which could overcome the high free space path loss in millimeter-wave [6]. The spacing between the elements are separated with a minimum distance between them so as to avoid mutual coupling between the elements which might affect the performance of the antenna [7].

2. Methodology

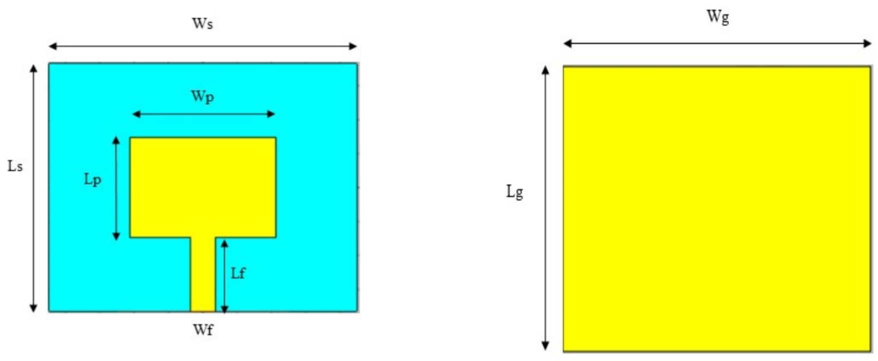
This chapter discusses the methodology and procedures that had been planned and applied throughout this work to obtain the desired results and thus, achieving the objectives. Due to the current Movement Control Order (MCO) imposed by the Government to curb the spread of COVID-19 in Malaysia, the nature of this work is purely based on simulations.

2.1 Antenna Design and Configuration

The antenna for 5G mobile communication at 28 GHz designed and simulated using CST MWS® software. The dimensions of the antennas are optimized to achieve the best result. A single element, two-element and four-element antennas are designed and simulated to operate at 28 GHz in this work to compare their gain and directivity. Microstrip feed line and inset feed line are implemented to observe their performances. The antenna is fabricated on Rogers RT5880 which has a dielectric constant, εr of 2.2, loss tangent, $\tan \delta$ of 0.0009 and thickness, h of 0.787 mm.

2.2 Design of Single Element Rectangular Microstrip Patch Antenna at 28 GHz

The first antenna is designed to operate at 28 GHz based on the calculation method [8]. Microstrip feed line is used in this design. Based on the calculation, the initial size of the antenna is 8.957×7.786 mm^2. However, the antenna dimensions do not produce the desired operating frequency at 28 GHz. Thus, the antenna needs to be optimized which has further reduced the size to 8.94×7.28 mm^2. The proposed antenna can be seen in Fig. 1. Dimensions of the antenna are listed in Table 1.



(a) (b)

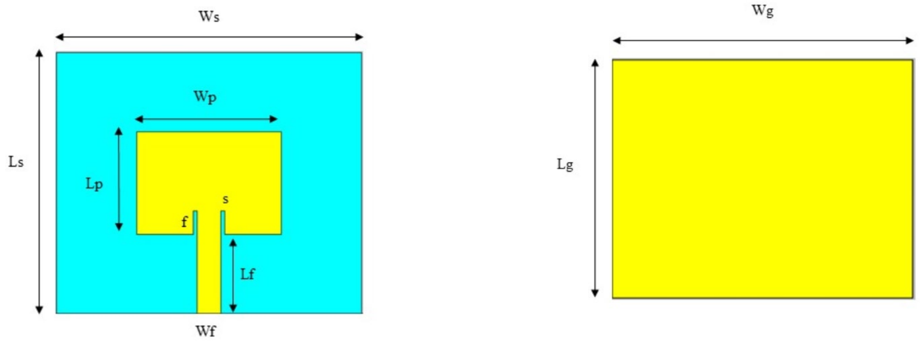
Fig. 1 - The proposed single element rectangular microstrip patch antenna at 28 GHz

Table 1 - Dimensions of the single element rectangular microstrip patch antenna at 28 GHz

Parameter	Values (mm)	Parameter	Values (mm)
W_s	8.94	W_f	0.71
L_s	7.28	L_f	2.23
W_p	4.21	W_g	8.94
L_p	2.94	L_g	7.28

2.3 Design of Single Element Inset Feed Rectangular Microstrip Patch at 28 GHz

The second antenna with an inset feed line is also designed to operate at 28 GHz based on the calculation method. The inset feed line is known to further improve the antenna's reflection coefficient. Initially, the size of the antenna is 8.957 × 7.786 mm^2 but reduced to 8.94 × 8.06 mm^2 after optimization. Fig. 2 shows the proposed antenna and Table 2 lists its dimensions.



(a) (b)

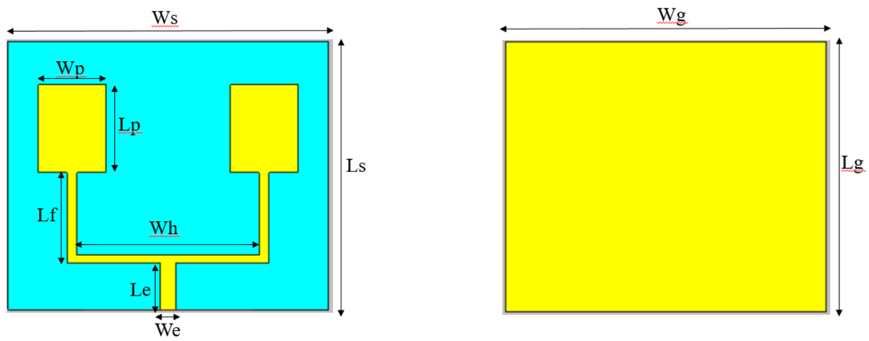
Fig. 2 - The proposed single element inset feed rectangular microstrip patch antenna at 28 GHz

Table 2 - Dimensions of the single element inset feed rectangular microstrip patch antenna at 28 GHz

Parameter	Values (mm)	Parameter	Values (mm)
W_s	8.94	W_f	0.69
L_s	8.06	L_f	3.53
W_p	4.3	W_g	8.94
L_p	3.2	L_g	8.06
S_i	0.12	L_i	1.1

2.4 Design of Two-Element Rectangular Microstrip Patch Antenna at 28 GHz

In this stage, a two-element rectangular microstrip patch antenna at 28 GHz is designed and simulated. Optimization is performed to obtain the desired operating at 28 GHz. Fig. 3 depicts the optimized design of two-element rectangular microstrip patch antenna. Based on parametric study, the size of the antenna increases from 8.9 × 8.0 mm^2 to 10 × 8.56 mm^2. Table 3 lists the optimized dimensions of the antenna.



(a) (b)

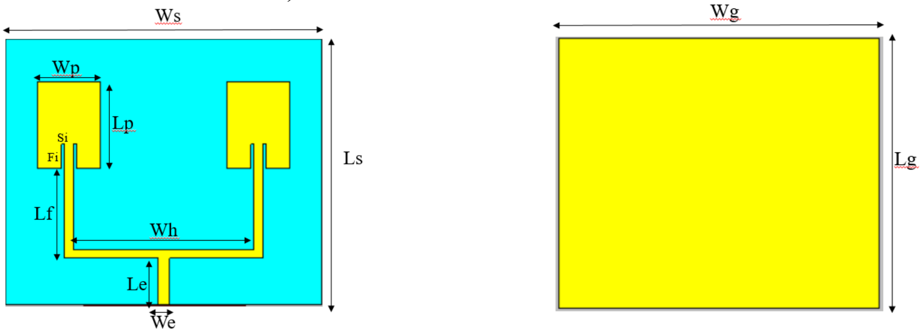
Fig. 3 - The proposed two-element rectangular microstrip patch antenna at 28 GHz

Table 3 - Dimensions of the two-element rectangular microstrip patch antenna at 28 GHz

Parameter	Values (mm)	Parameter	Values (mm)
W_s	10	L_e	1.50
L_s	8.56	W_h	6.30
W_p	2.10	L_f	2.87
L_p	2.82	L_g	8.56
W_e	0.5	W_g	10

2.5 Design of Two-Element Inset Feed Rectangular Microstrip Patch Antenna at 28 GHz

Next, a two-element inset feed rectangular microstrip patch antenna is designed and simulated to operate at 28 GHz. The antenna is once again optimized. Fig. 4 shows the optimized design of two-element inset feed rectangular microstrip patch antenna. On the other hand, Table 4 lists the dimensions of the antenna.



(a) (b)

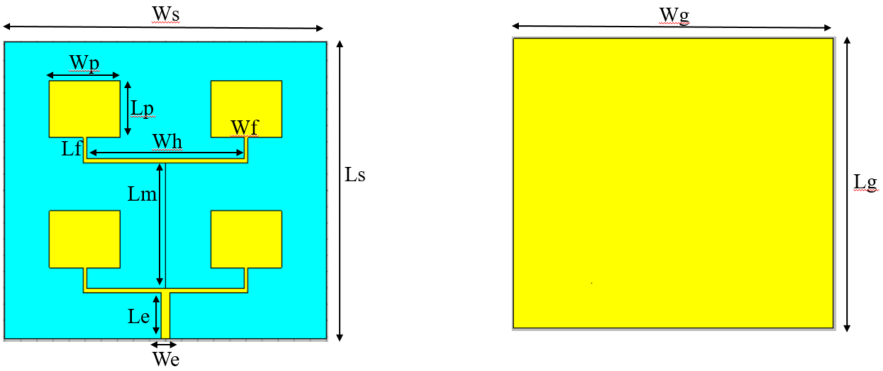
Fig. 4 - The proposed two-element inset feed rectangular microstrip patch antenna at 28 GHz

Table 4 - Dimensions of the two-element inset feed rectangular microstrip patch antenna at 28 GHz

Parameter	Values (mm)	Parameter	Values (mm)
W_s	10	L_e	1.50
L_s	8.52	W_h	5.73
W_p	1.98	L_f	3.65
L_p	2.79	L_g	8.52
W_e	0.38	W_g	10
S_i	0.10	F_i	0.79

2.6 Design of Four-Element Rectangular Microstrip Patch Antenna at 28 GHz

In the section, a four-element rectangular microstrip patch antenna is designed and simulated to operate at 28 GHz. Fig. 5 shows the optimized dimensions of four-element rectangular microstrip antenna patch antenna. The size of the antenna increases from the initial size of 10 × 8.5 mm^2 to 20 × 18.26 mm^2. Table 5 lists the dimensions of the antenna.



(a) (b)

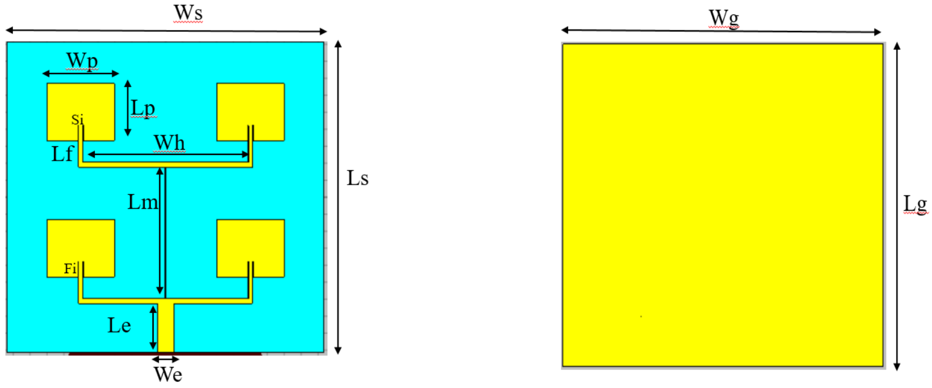
Fig. 5 - The proposed four-element rectangular microstrip patch antenna at 28 GHz

Table 5 - Dimensions of the four-element rectangular microstrip patch antenna at 28 GHz

Parameter	Values (mm)	Parameter	Values (mm)
W_s	20	L_e	3.03
L_s	18.26	W_h	9.76
W_p	4.40	L_f	1.56
L_p	3.50	L_g	18.26
W_e	0.5	W_g	20
L_m	7.72		

2.7 Design of Four-Element Inset Feed Rectangular Microstrip Patch Antenna at 28 GHz

In the final stage, a four-element inset feed rectangular microstrip patch antenna is designed and simulated to operate at 28 GHz. The optimized design of the antenna can be viewed in Fig. 6. Based on parametric study, the size of the antenna decreases from its initial size of 20 × 18.26 mm^2 to 18.67 × 18.26 mm^2. Table 6 lists the optimized dimensions of the antenna.



(a) (b)

Fig. 6 - The proposed four-element inset feed rectangular microstrip patch antenna at 28 GHz

Table 6 - Dimensions of the four-element inset feed rectangular microstrip patch antenna at 28 GHz

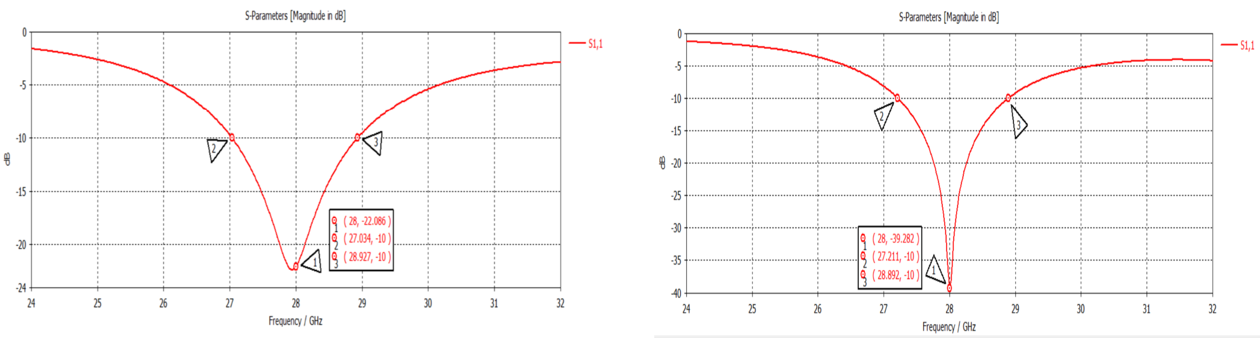
Parameter	Values (mm)	Parameter	Values (mm)
W_s	18.67	L_e	3.12
L_s	18.26	W_h	9.76
W_p	3.98	L_f	2.45
L_p	3.35	L_g	18.26
W_e	0.98	W_g	18.67
L_m	7.72	S_i	0.89
F_i	0.04		

3. Results and Analysis

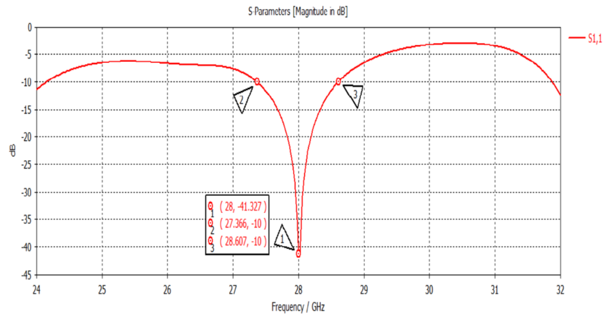
In this section, the linear characteristics of the antennas are simulated and the results are discussed and analyzed. The comparison are also performed between the antennas with a microstrip feed line and inset feed line.

3.1 Reflection Coefficient and Bandwidth

The simulated reflection coefficient of the rectangular microstrip patch antenna at 28 GHz for a single element, two-element and four-element can be viewed in Fig. 7. From Fig. 7(a), the reflection coefficient, S_{11} of the single element antenna is -22.08 dB at 28 GHz. The -10-dB bandwidth of the antenna can be calculated from the difference between the upper and lower frequency at -10-dB and it is found to be 1893 MHz. From Fig. 7(b), the reflection coefficient of the two-element antenna at 28 GHz increases to -39.28 dB with a bandwidth of 1681 MHz. Lastly, the reflection coefficient of the four-element antenna at 28 GHz, which can be viewed in Fig. 7(c), further increases to -41.32 dB while the bandwidth of the antenna is 1241 MHz. Based on the results, the reflection coefficient increases as the number of elements on the antenna increases.



(a) (b)

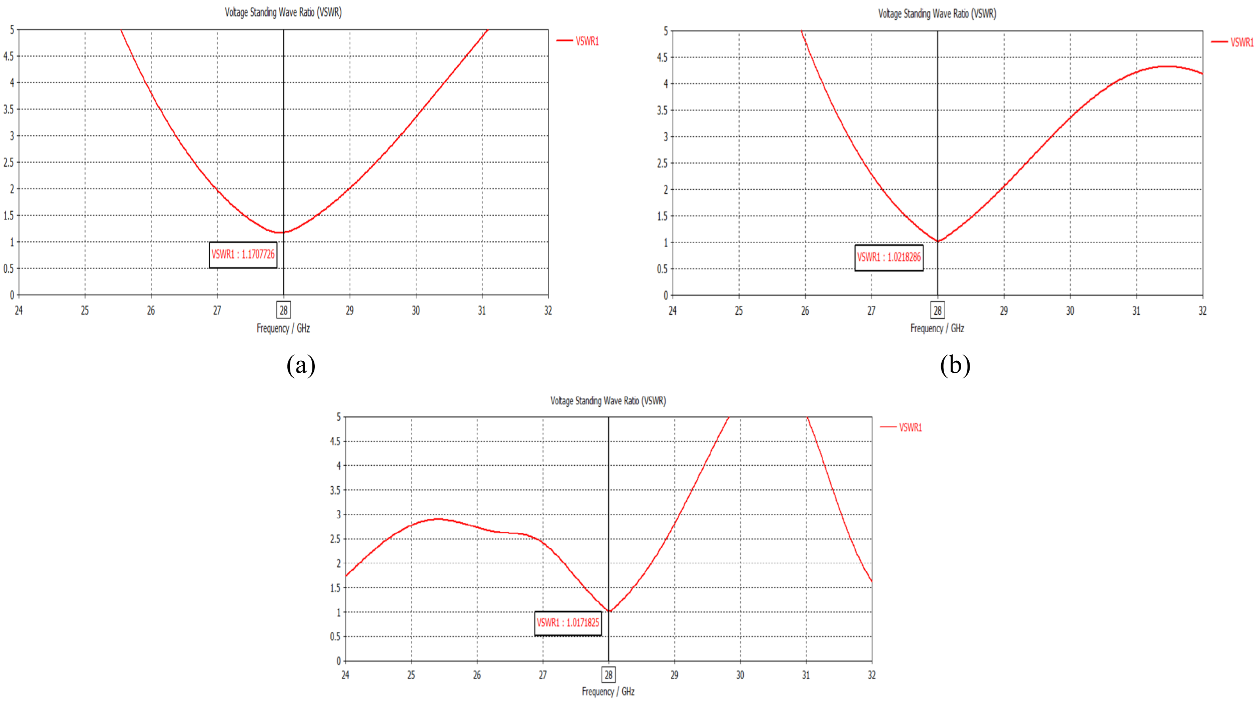


(c)

Fig. 7 - Simulated reflection and bandwidth of the rectangular microstrip patch antenna at 28 GHz for; (a) single element (b) two-element (c) four-element

3.2 Voltage Standing Wave Ratio

Fig. 8 shows the simulated Voltage Standing Wave Ratio, VSWR of the antennas at 28 GHz. It can be seen from Fig. 8(a) that VSWR for the single element antenna is 1.170. From Figure 8(b), VSWR for the two-element antenna is 1.021. VSWR is 1.017 for the four-element antenna as can be viewed in Fig. 8(c). The magnitudes of VSWR which is less than 2.0 show that the antennas operate well at the resonant frequency of 28 GHz.



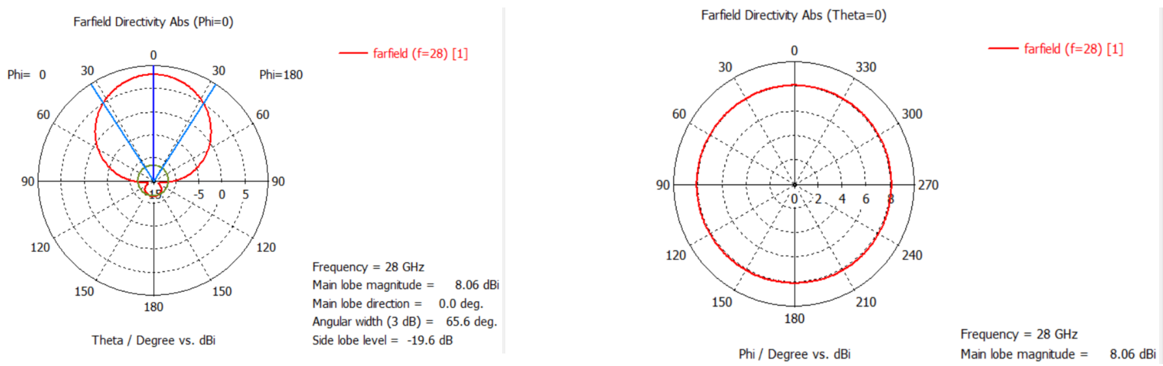
(a) (b)

(c)

Fig. 8 - VSWR of the rectangular microstrip patch antenna for; (a) single element (b) two-element (c) four-element

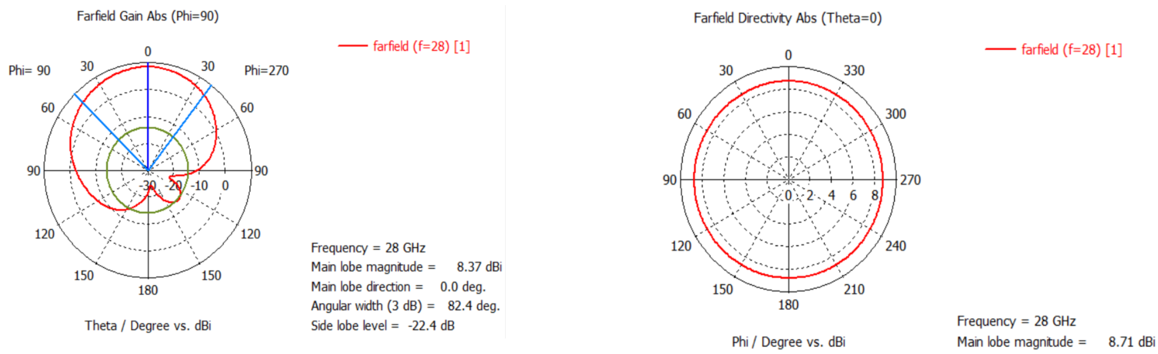
3.3 Radiation Pattern

Radiation patterns of the rectangular microstrip patch antenna for a single element, two-element and four-element in the *E*-plane and *H*-plane can be viewed in Fig. 9, Fig. 10 and Fig. 11. From Fig. 9(a), the radiation pattern for the single element antenna is unidirectional in the *E*-plane with the main lobe magnitude of 8.06 dBi while in Fig. 9(b), an omnidirectional radiation pattern is observed in the *H*-plane with a similar main lobe magnitude of 8.06 dBi. Next, from Fig. 10(a), the radiation pattern for the two-element antenna is unidirectional in the *E*-plane with the main lobe magnitude of 8.37 dBi while in Fig. 10(b), an omnidirectional radiation pattern is observed in the *H*-plane with the main lobe magnitude of 8.71 dBi. Last but not least, from Fig. 11(a), a unidirectional pattern can also be seen in the *E*-plane for the four-element antenna with a greater main lobe magnitude of 9.82 dBi while in Fig. 11(b), an omnidirectional radiation pattern is observed in the *H*-plane the main lobe magnitude of 9.12 dBi. Based on the results, the main lobe magnitude increases as the number of elements on the antenna increases.



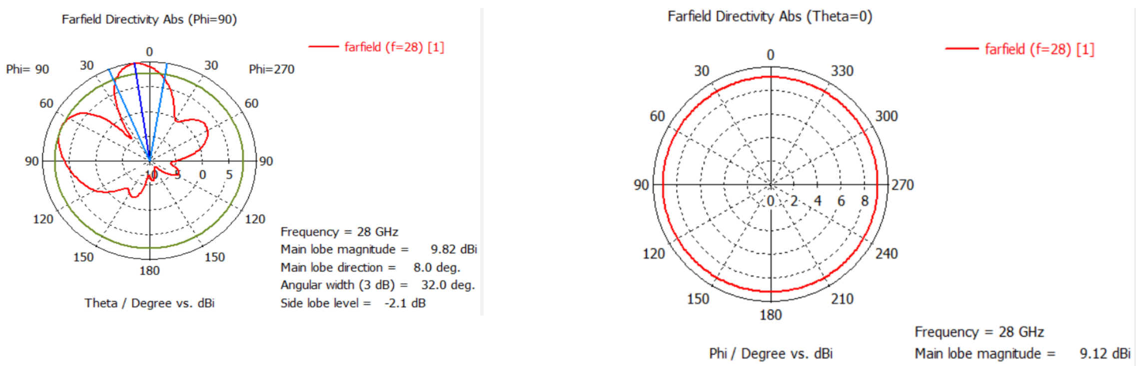
(a) (b)

Fig. 9 - Radiation pattern of the single element rectangular microstrip patch antenna in the; (a) *E*-plane (b) *H*-plane



(a) (b)

Fig. 10 - Radiation pattern of the two-element rectangular microstrip patch antenna in the; (a) *E*-plane (b) *H*-plane

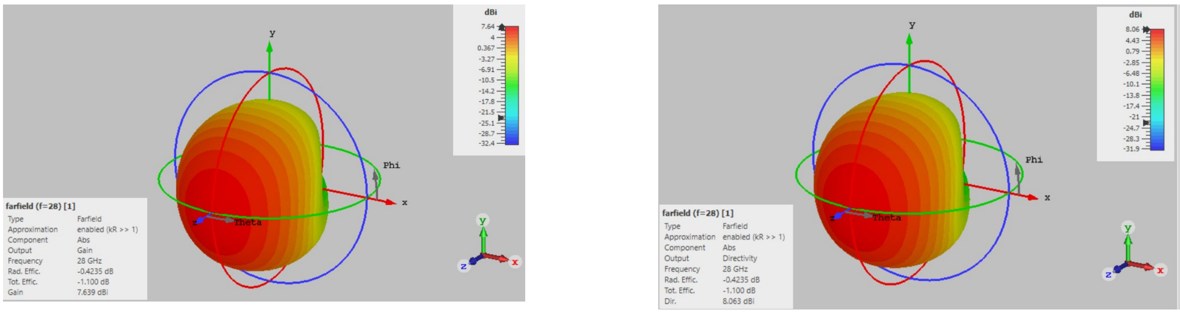


(a) (b)

Fig. 11 - Radiation pattern of the four-element rectangular microstrip patch antenna in the; (a) *E*-plane (b) *H*-plane

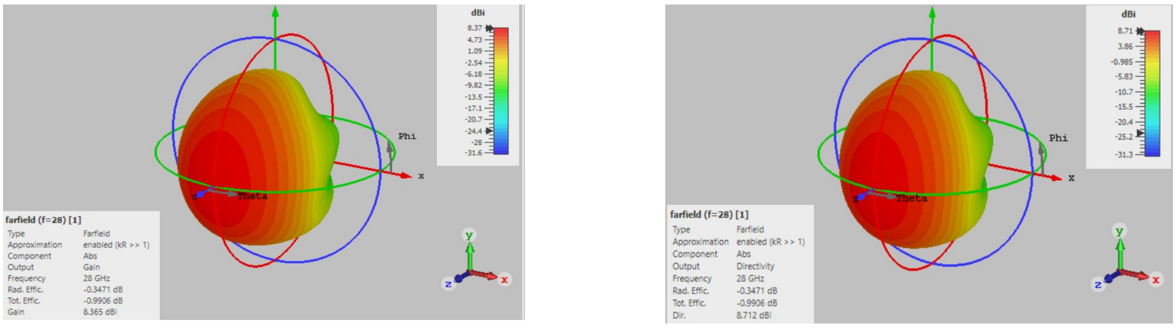
3.4 Gain, Directivity and Efficiency

The gain and directivity of the single element, two-element and four-element antennas can be viewed in the 3D polar graph in Fig. 12, Fig. 13 and Fig. 14. The efficiency in percentage can be calculated from the total efficiency from the same 3D polar graph. From Fig. 12(a), the gain, G for the single element antenna at 28 GHz is 7.639 dBi while from Fig. 12(b), the directivity, D is 8.063 dBi. The calculated efficiency is 77.62%. Next, for the two-element antenna, the gain and directivity and can be viewed in Fig. 13. It can be seen from Fig. 13(a) and 13(b) that the gain is 8.365 dBi and directivity is 8.712 dBi. The calculated efficiency is 79.60%. Lastly, for the four-element antenna, the gain and directivity from Fig. 14(a) and Fig. 14(b) are 8.931 dBi and 9.773 dBi. The calculated efficiency is 82.37%. Based on the results obtained, the gain, directivity and calculated efficiency increase as the number of elements on the antenna increases.



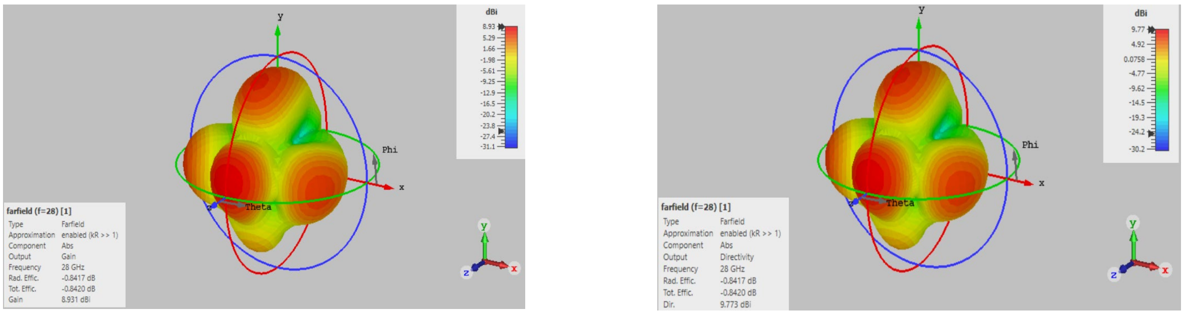
(a) (b)

Fig. 12 - Gain, directivity and efficiency of the single element rectangular microstrip patch antenna



(a) (b)

Fig. 13 - Gain, directivity and efficiency of the two-element rectangular microstrip patch antenna

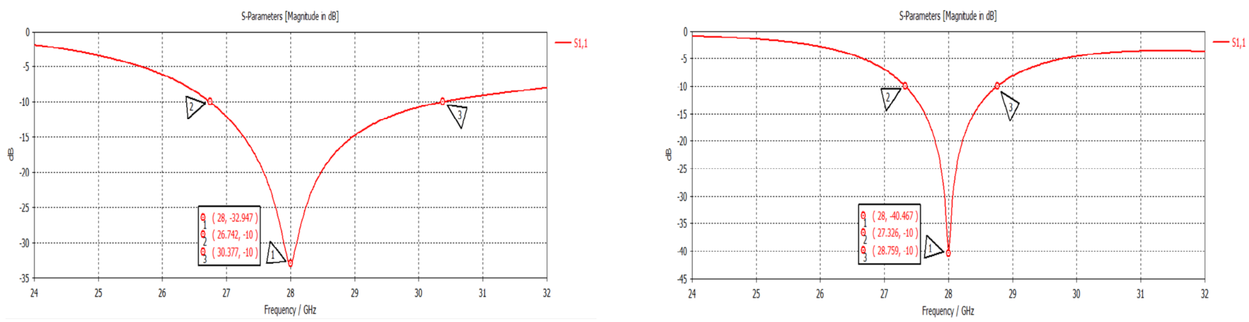


(a) (b)

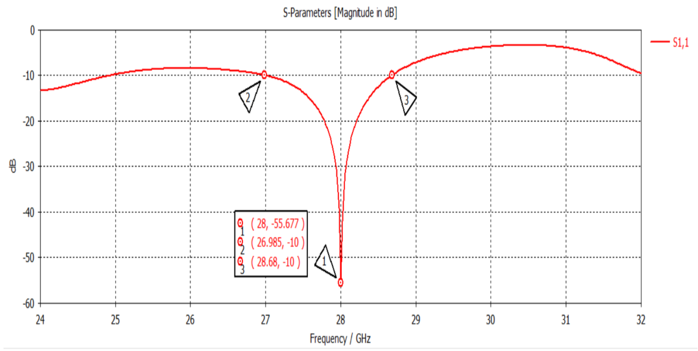
Fig. 14 - Gain, directivity and efficiency of the four-element rectangular microstrip patch antenna

3.5 Reflection Coefficient and Bandwidth

This section onwards discuss the linear characteristics of inset feed rectangular microstrip patch antenna. The simulated reflection coeffiecient of the inset feed rectangular microstrip patch antenna at 28 GHz for a single element, two-element and four-element can be viewed in Fig. 15. From Fig. 15(a), the reflection coefficient, S_{11} of the single element antenna is -32.94 dB and the bandwidth is 3628 MHz. Next, for the two-element antenna can be viewed in Fig. 15(b), the reflection coefficient is -40.46 dB which is greater than the reflection coefficient of a single element antenna. The bandwidth, on the other hand, is 1433 MHz. Lastly, the reflection coefficient for the four-element antenna can be viewed in Fig. 15(c). From the figure, the reflection coefficient is -55.67 dB and the bandwidth is 1.695 GHz. From the results, the reflection coefficient increases as the number of elements on the antenna increases.



(a) (b)

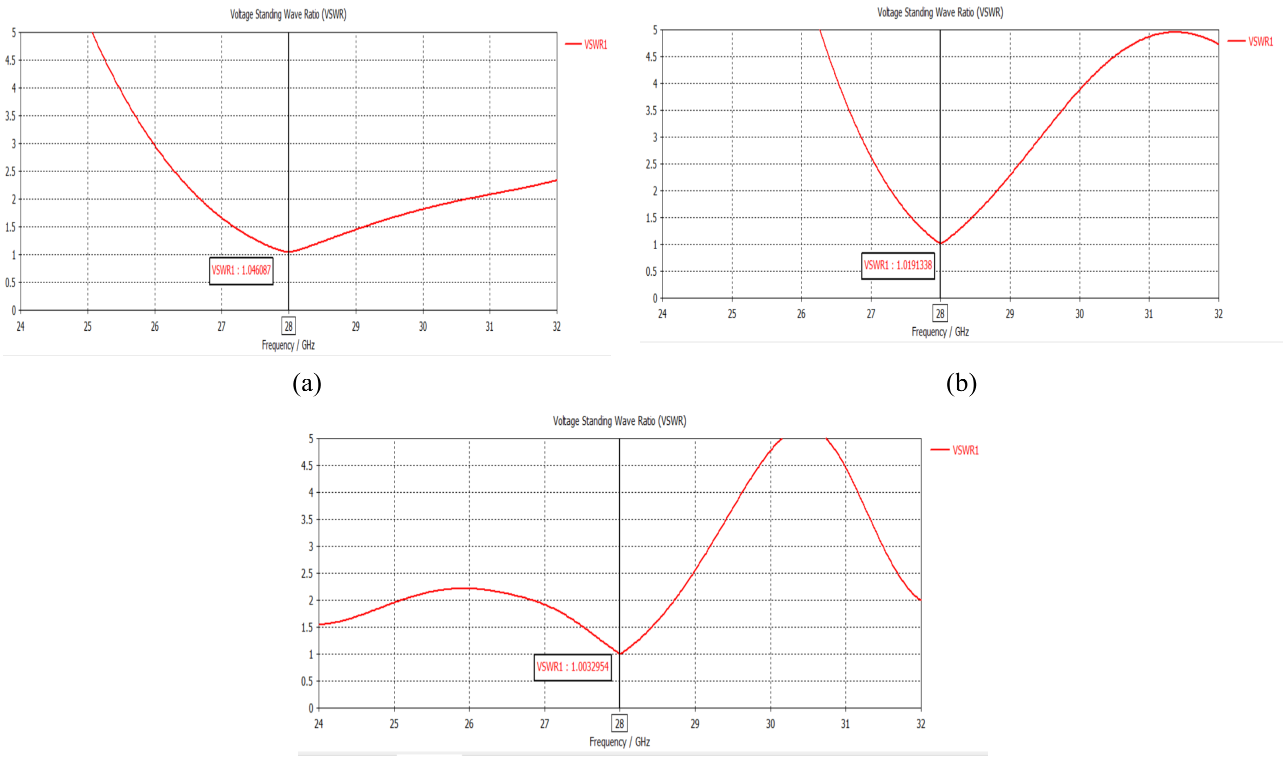


(c)

Fig. 15 - Simulated reflection and bandwidth of the inset feed rectangular microstrip patch at 28 GHz for; (a) single element (b) two-element (c) four-element

3.6 Voltage Standing Wave Ratio

Fig. 16 shows the simulated Voltage Standing Wave Ratio, VSWR of the antennas at 28 GHz. From Fig. 16 (a), VSWR for the single element antenna is 1.046. From Fig. 16(b), VSWR for two-element antenna is 1.019. VSWR for the four-element antenna is 1.003 which can be viewed in Fig. 16(c). The VSWR ≤ 2.0 shows that the antennas operate well at the resonant frequency of 28 GHz.



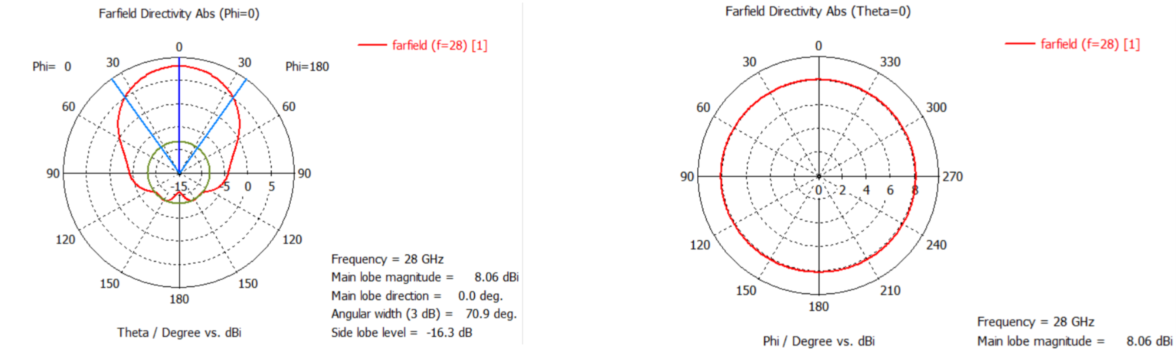
(a) (b)

(c)

Fig. 16 - VSWR of the inset feed rectangular microstrip patch antenna for; (a) single element (b) two-element (c) four-element

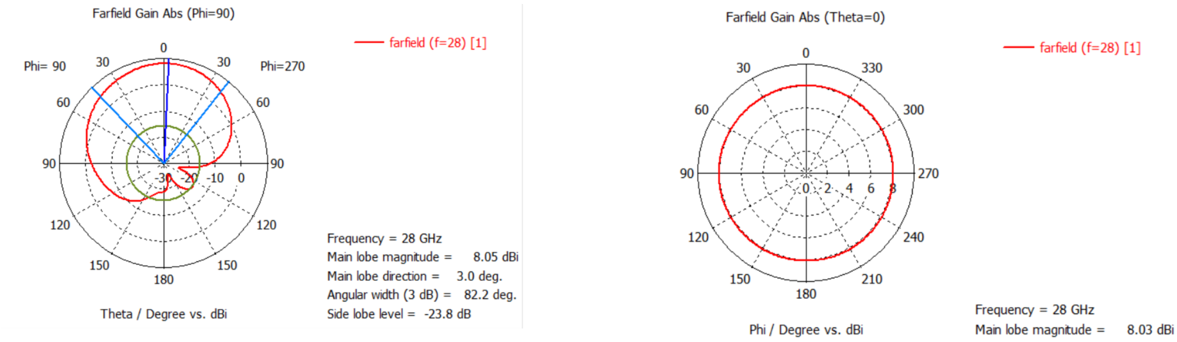
3.7 Radiation Pattern

Radiation patterns of the inset feed rectangular microstrip antenna patch for a single element, two-element and four-element in the *E*-plane and *H*-plane can be seen Fig. 17, Fig. 18 and Fig. 19. For the single element antenna in Fig. 17(a), radiation pattern is unidirectional in the *E*-plane with the main lobe magnitude of 8.06 dBi while in Fig. 17(b), an omnidirectional radiation pattern is observed in the *H*-plane with a similar main lobe magnitude of 8.06 dBi. From Fig. 18(a), for the two-element antenna, radiation pattern is unidirectional in the *E*-plane with the main lobe magnitude of 8.05 dBi while in Fig. 18(b), an omnidirectional radiation pattern is observed in the *H*-plane with the main lobe magnitude of 8.03 dBi. Lastly, for the four-element antenna as can be viewed in Fig. 19(a), radiation pattern is unidirectional in the *E*-plane with the main lobe magnitude of 11.5 dBi and an omnidirectional radiation pattern is observed in the *H*-plane with the main lobe magnitude of 11.1 dBi as in Fig. 19(b). Based on the results, the main lobe magnitudes are almost similar for the single and two-element antennas and increases greatly when it comes to the four-element antenna.



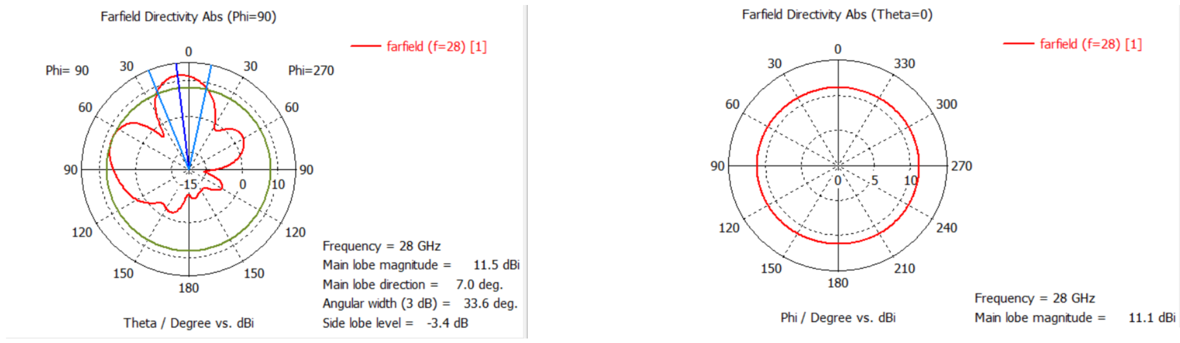
(a) (b)

Fig. 17 - Radiation pattern of the single element inset feed rectangular microstrip patch antenna in the; (a) *E*-plane (b) *H*-plane



(a) (b)

Fig. 18 - Radiation pattern of the two-element inset feed rectangular microstrip patch antenna in the; (a) *E*-plane (b) *H*-plane

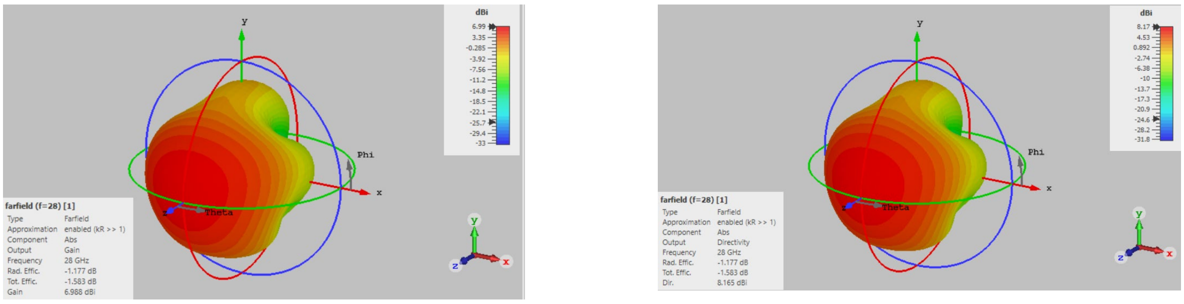


(a) (b)

Fig. 19 - Radiation pattern of the four-element inset feed rectangular microstrip patch antenna in the; (a) *E*-plane (b) *H*-plane

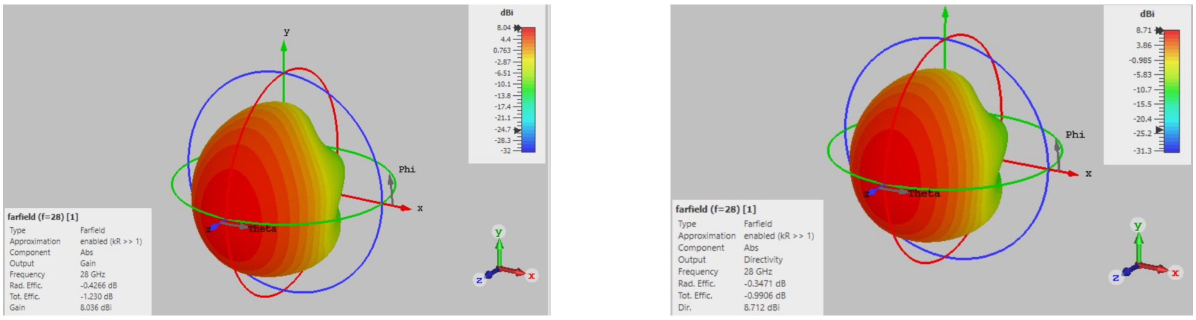
3.8 Gain, Directivity and Efficiency

The gain and directivity of the single element, two-element and four-element antennas can be seen in Fig. 20, Fig. 21 and Fig. 22. Similarly, the efficiency in percentage can be calculated based on the total efficiency in the 3D polar graph from those figures. From Fig. 20(a) and Fig. 20(b), the gain, G and directivity, D for the single element antenna are 6.988 dBi and 8.165 dBi. The calculated efficiency, η (%) is 69.45%. Next, for the two-element antenna, the gain and directivity based on Fig. 21(a) and Fig. 21(b) are 8.036 dBi and 8.712 dBi. On the other hand, the calculated efficiency is 75.33%. Lastly, the gain and directivity for the four-element antenna as can be viewed in Fig. 22(a) and Fig. 22(b) are 10.86 dBi and 11.49 dBi. The calculated efficiency is 86.44%. Therefore, it can be seen as a whole that the gain, directivity and efficiency increase as the number of elements on the antenna increases.



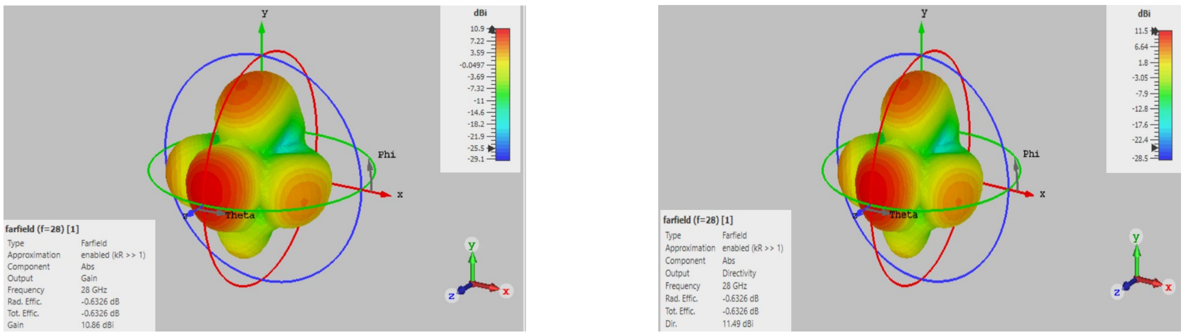
(a) (b)

Fig. 20 - Gain, directivity and efficiency of the single element inset feed rectangular microstrip patch antenna



(a) (b)

Fig. 21 - Gain, directivity and efficiency of the two-element inset feed rectangular microstrip patch antenna



(a) (b)

Fig. 22 - Gain, directivity and efficiency of the four-element inset feed rectangular microstrip patch antenna

3.9 Comparison between the Single Element, Two-Element and Four-Element Rectangular Microstrip Patch Antennas for Microstrip and Inset Feed Lines

Table 7 compares the dimensions (or the size of antenna), reflection coefficient, gain and directivity of all the simulation results of the single element, two-element and four-element rectangular microstrip patch antenna for both microstrip feed line and inset feed line to observe the trend in reflection coefficient, gain and directivity. From the table, the gain and directivity increase from a single element up until four-element array antennas. This confirm to the fact that array antenna produces high gain and directivity which could overcome the challenge of high free space path loss in millimeter-wave. The reflection coefficient also increases as the number of elements on the antenna increases. This is due to the design of array antennas (two-element and four-element) which are spaced accordingly between each element and not so close with each other in order to suppress the mutual coupling between the elements. In terms of dimensions, it can be seen that there are size reductions for the antennas with an inset feed line as compared to microstrip feed line as the number of elements increases. Thus, it can also be concluded from the table that inset feed line antennas perform better than microstrip feed line antennas when it comes to gain, directivity, reflection coefficient, and dimensions of antennas.

Table 7 - Comparison between the Rectangular Microstrip Patch Antennas for Microstrip Feed Line and Inset Feed Line at 28 GHz

	Microstrip Feed Line			Inset Feed Line		
	Single element	**Two-element**	**Four-element**	**Single element**	**Two-element**	**Four-element**
Dimensions (mm^2)	8.9 × 7.7	10 × 8.56	20 × 18.26	8.9 × 8.0	10 × 8.52	18.67 × 18.26
Reflection Coefficient (dB)	-22.08	-39.28	-41.32	-32.94	-40.40	-55.63
Gain (dBi)	7.639	8.365	8.931	6.988	8.036	10.86
Directivity (dBi)	8.063	8.712	9.773	8.165	8.463	11.49

Conclusion

This work presents the antennas for 5G mobile communication at 28 GHz on Rogers RT5880 with a dielectric constant, εr of 2.2, loss tangent, tan δ of 0.0009 and thickness, h of 0.787 mm. A rectangular microstrip patch antenna is proposed in this work which consists of a single element and array configurations with two and four elements. Microstrip feed line and inset feed line are implemented to observe their performances. It can be observed from the simulation results that the gain and directivity increase from a single element up until the four elements array antenna for both the microstrip feed line and inset feed line of the rectangular microstrip patch antenna. The gain of the microstrip feed line rectangular patch antenna increases from 7.639 dBi to 8.931 dBi and the directivity also increases from 8.0631 dBi to 9.773, for a single element up to two-element and four-element. For inset feed rectangular patch antenna, the gain increases from 6.988 dBi to 10.86 dBi. The directivity also increases from 8.165 dBi to 11.49 dBi. This confirm to the fact that array antenna produces high gain and directivity which could overcome the challenge of high free space path loss in millimeter-wave. The spacing between each element in the array antenna are spaced accordingly and not so close with each other in order to suppress the mutual coupling between the elements. It is shown that the mutual coupling is greatly reduced based on the greater values of reflection coefficient in two-element and four-element array antennas. The reflection coefficient of a microstrip feed line and inset feed line antennas increases from -39.28 dB to -41.32 dB and from -40.40 dB to -55.63 dB, for a single element up to two-element and four-element. Thus, based on the results obtained from the gain, directivity and reflection coefficient, inset feed line antennas perform better than microstrip feed line antennas. In terms of dimensions, it can be observed that the size of the antenna is smaller for the antennas with an inset feed line as compared to microstrip feed line as the number of elements increases. Hence, it can be concluded that inset feed line antennas outperform microstrip feed line antennas when it comes to gain, directivity, reflection coefficient and dimensions of antennas. Therefore, the proposed array antennas in this work are suitable to be used in 5G mobile communications.

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